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RADAR BULLETIN NO. 1 A

(RADONE A)

THE CAPABILITIES AND LIMITATIONS OF SHIPBORNE RADAR

UNITED STATES FLEET
HEADQUARTERS OF THE COMMANDER IN CHIEF

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UNITED STATES FLEET
HEADQUARTERS OF THE COMMANDER IN CHIEF
NAVY DEPARTMENT
WASHINGTON 25, D. C.

25 July, 1945

LETTER OF PROMULGATION

1. This publication, the CAPABILITIES AND LIMITATIONS OF SHIPBORNE RADAR, is issued for the use and guidance of the United States Fleet. Its principal purpose is to explain how radar operation is affected by the many variables to which it is subject.

2. This publication is effective upon receipt and supersedes Radar Bulletin No. 1 (RADON), "The Tactical Use of Radar," all copies of which shall be destroyed by burning. No report of destruction is required.

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C. M. COOKE, JR.,
Chief of Staff.

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TABLE OF CONTENTS

	Page
Promulgating Letter	i
Distribution List	ii
Table of Contents	iii
Chapter I—Introduction	1
Chapter II—Theory of Radar	7
Chapter III—Capabilities of Radar	21
Chapter IV—Limitations Imposed on Radar by External Factors	61
Chapter V—Limitations Inherent in Radar Equipment	83
Chapter VI—Operational Limitations on Radar	111
Chapter VII—Limitations Imposed on Radar by Enemy Countermeasures	131
Chapter VIII—Repeater Plan Position Indicators	141
Chapter IX—Radar Recognition Systems—IFF	151
Chapter X—Radar Beacons—RACON	167
Appendix A—Glossary of Radar Terms	171
Index	203

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CHAPTER I

INTRODUCTION

A. General
B. Purpose — relation to rest of RAD series
C. Radar Terms
D. Frequency bands
E. Radar nomenclature

A. GENERAL

The subject of radar is rather complex because of its technical nature and because it is still a new and rapidly growing field. A full appreciation of exactly how much radar can do and of how much it cannot do must therefore be based on an understanding of the many technical factors that influence radar operation. However, it has been attempted in this book to explain many of these considerations in relatively simple terms in order to make clear the capabilities and limitations of naval shipborne radar to personnel who have limited technical knowledge.

B. PURPOSE

The purpose of RADONE-A is somewhat different from that of the original RADON which it supersedes. All of the material on the tactical applications of radar has been removed, since RADFOUR, *Air Plotting Manual,* RADFIVE, *Surface Plotting Manual,* RADSIX, *CIC Manual,* RADEIGHT, *Aircraft Control Manual,* and RADNINE, *Tactical Uses of Radar in Small Vessels,* will contain this information in more complete and more modern form than was possible at the time that RADON was prepared. RADTWO, *The Tactical Use of Radar in Aircraft,* is being modernized but it will retain approximately the same scope as the first edition. RADTHREE, *Radar Operator's Manual,* describes the manipulation of controls and presents other data essential to the radar operator. RADSEVEN, which will be available some time in 1945, will be entitled *Radar Countermeasures Manual.* In addition to the foregoing, there are three other manuals in preparation for inclusion in the RAD series. They are to be: RADTEN, *Airborne Radar Operator's Manual;* RADELEVEN, *Shipborne Radar Countermeasures Operator's Manual;* and RADTWELVE, *Airborne Radar Countermeasures Operator's Manual.*

The purposes of the present edition of RADONE, then, are:

1. To describe the principles of operation of radar, IFF, beacons, and repeater indicators.

2. To furnish pertinent information about the characteristics and capabilities of radar, IFF, and beacons now in the fleet, and shortly to be available.

3. To explain the limitations imposed on the operation of radar, IFF, and beacons by: the properties of radio waves; uncontrollable factors, external to the equipment, such as the weather; inherent electrical and mechanical shortcomings of the equipment; operational difficulties; and enemy use of countermeasures.

It is expected that the material in this book will be of interest primarily to commanding officers, executive officers, and CIC Watch Officers in all ships of the Navy. However, much of the book will be of value not only to the radar operators, but also to all personnel who have an interest in the operational aspect of radar.

C. RADAR TERMS

Although radar has been in existence only a short time, a vocabulary of special terms has grown up with its development. As in any other art, it is difficult to gain a complete understanding of radar without first learning a few of the basic terms of its special language. Therefore, it is desirable to discuss a few terms that are frequently used before beginning explanation of radar. A fairly complete glossary of radar terms is included at the end of this book as Appendix A.

The unit of time most frequently used with radar is the *microsecond.* A microsecond is one-millionth of a second. It is abbreviated as μs or μsec, and generally used in calculation as 10^{-6} second.

A *pulse* is a sudden change of voltage or current of short duration; the pulse transmitted by a radar is produced by suddenly causing a normally quiescent circuit to generate radio-frequency energy during a very short interval of time. The *pulse duration* of the radar is the time during which the transmitter is actually generating radio-frequency energy in each cycle of operation. The number of pulses that are transmitted each second is called the *pulse repetition rate,* which is often abbreviated PRR. These quantities are indicated in figure 1A.

A *radio-frequency pulse* is a short burst of radio-frequency energy. The pulses transmitted and received

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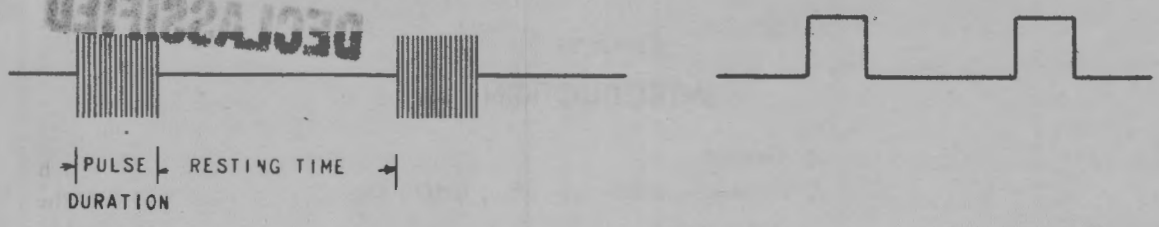

A. RF PULSES B. VIDEO PULSES

Figure 1—Radar pulses.

by the radar are radio-frequency pulses. The term *video* is borrowed from television, where it refers to the signals that produce the visible picture. A *video pulse* in radar is a similar signal. It is a unidirectional pulse—one in which the voltage does not alternate—that is derived from the receiver and used to produce the echo indication (fig. 1B).

The *peak power* of a radar is the power transmitted during the pulse. There is nothing transmitted during the resting time between pulses. Since the pulse duration is a very small fraction of the pulse repetition time, the average of the power transmitted over a complete cycle is small. However, the power transmitted during the pulse is large; peak power is measured in kilowatts or megawatts.

The device on which the echo signals are displayed in a radar system is a *cathode-ray oscilloscope*. The screen on which the echoes are viewed is usually called simply the *scope*. The time base on which the ranges of echoes are measured is produced by a current or voltage called a *sweep*.

The *resolution* of a radar is the separation between two targets required to permit the range, bearing, or altitude of either target to be determined with normal accuracy independently of the other target. Thus, *range resolution* is the minimum range difference between two targets that will allow the operator to obtain data on either of two targets on the same bearing. *Bearing resolution* is a similar quantity which expresses the minimum required bearing difference for two targets at the same range.

The electromagnetic field leaving a radar antenna varies continually in intensity because the current that produces it alternates at the frequency of the radar transmitter. This alternating field travels away from the antenna at the speed of light, producing a cyclic variation of the field intensity in space. The distance in which a complete cycle of the variation occurs is called the *wavelength* of the radio-frequency energy. The field intensities at two points a half-wavelength apart are equal in magnitude but they are always of opposite polarity, or 180° out of phase. In radar, wavelength is measured in meters or centimeters, and it is denoted by the Greek letter λ (lambda). Frequency and wavelength are used interchangeably in radar, depending on which is the more convenient. They are related by the expression

$$\lambda = \frac{300}{f}$$

in which λ is measured in meters, f is the frequency in megacycles, and the constant is the velocity of light in meters per microsecond.

D. FREQUENCY BANDS

If the exact frequencies on which all of the Navy's radars operate were widely known, the enemy would soon learn this very important information. This knowledge would simplify the development of effective countermeasures to our radar.

Therefore, five frequency bands denoted by code letters have been established. These five bands, in order of increasing frequency, are P, L, S, X, and K. Within each of these broad bands, relatively narrow frequency bands have been established for the operation of specific radar equipments. These narrow bands are denoted by a subscript letter on the basic letter, as S_w, for example. Radio frequencies may sometimes be indicated also by the system given below:

Very low frequency	— VLF	10 — 30 Kilocycles
Low frequency	— LF	30 — 300 Kilocycles
Medium frequency	— MF	300 — 3000 Kilocycles
High frequency	— HF	3 — 30 Megacycles
Very high frequency	— VHF	30 — 300 Megacycles
Ultra high frequency	— UHF	300 — 3000 Megacycles
Super high frequency	— SHF	3000 — 30,000 Megacycles

Only the VHF, UHF, and SHF bands are used in radar. A third, and even more general, way of referring to the operating frequencies is to break them down into only two categories. Frequencies above approximately 600 megacycles per second, which have wavelengths shorter than 50 centimeters, are often referred to as *microwave* or *centimeter wave*. Wavelengths longer than 50 centimeters are called *meter wave* or *long wave* (for radar). Thus, the K, X, and S bands are microwave and the P band is long wave, but the L band covers the region between the two.

It is not important for either the operating or maintenance personnel to know the exact wavelength of a particular radar, beyond knowing the band in which it operates. In most equipment, test gear is

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provided which is calibrated simply from 0 to 100, or with some such arbitrary scale. Since only relative measurements need be made on the equipment, such scales are entirely satisfactory, and they prevent the disclosure of the actual operating frequency to anyone —friend or enemy. Operating personnel should know the frequency band in which each set operates in order that they may realize the full capabilities of the equipment and understand the limitations imposed by the radio frequency transmitted. Neither the capabilities nor the limitations which are functions of frequency vary appreciably over a single band. However, there is a marked difference in the performance of an X-band radar compared to a P-band radar, for example.

E. RADAR NOMENCLATURE

The model designation of shipboard radar is intended to indicate in a general way the use to which the equipment is to be put. Except for fire control radar, which is given a "Mark" designation, the following letters are used to indicate application:

S—search
B—recognition
Y—navigational aid
A—prefix indicating airborne installation.

For example, the SC, SK, SG, and SR are search radars. The second letter indicates approximately the order in which the equipment was developed. Improved models of a particular radar are designated by a letter or a number after the model designation, as SG-a, SG-1, and SG-3. The ABK is an airborne identification equipment, while the BK, BL, and BN are recognition equipments used on board ship. The YJ is a radar beacon, or *racon,* used to help airplanes to navigate back to a carrier or to a land base.

Airborne radar, beacons challenged by airplanes, radar countermeasures equipment, and other equipment used jointly by the Navy, Army, and Allied forces is designated by means of the AN nomenclature system. A chart explaining this system is given in Figure 2, and an article in the *CIC Magazine* for December, 1944 (Vol. I, No. 9) and in the *Radio and Sound Bulletin,* No. 17, January, 1945, may provide further explanation.

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EXAMPLE OF COMPONENT TYPE NUMBER: T - 2 B /

	RADIO TRANSMITTER	2	B (See Note 3)	PART OF OR USED WITH
	TABLE OF COMPONENT INDICATORS	NUMBER	MODIFICATION LETTER	SLANT

Comp. Ind.	Family Name	Definition or Example *Not to be construed as limiting the application of the component indicator to those items.*
AB	Antenna Supports	Antenna mounts, mast bases, mast sections, towers, etc.
AM	Amplifiers	Power, audio, interphone, radio frequency, panoramic, etc..
AS	Antenna Assemblies	Complex: Arrays, parabolic type, masthead, etc.
AT	Antennae	Simple: Whip or telescopic, loop, dipole, reflector, etc.
BA	Battery, primary type	B-batteries, battery packs, etc.
BB	Battery, secondary type	Storage batteries, battery packs, etc.
BZ	Audible Signal Devices	Buzzers, gongs, horns, etc.
C	Control Articles	Control box, remote tuning control, control unit, etc.
CG	R.F. Cables & Transmission Line	R.F. cables, wave guides, etc., with terminals.
CK	Crystal Kits	A kit of crystal units.
CM	Comparators	Analyzes or compares two or more input signals.
CN	Compensators	Electrical &/or mechanical compensating, regulating or attenuating apparatus.
CP	Computers	A mechanical &/or electronic mathematical calculating unit.
CR	Crystal Units	Crystal in crystal holder.
CU	Coupling Units	Impedance coupling devices, directional couplers, etc.
CV	Converters (electronic)	Electronic apparatus for changing the phase, frequency, or from one medium to another.
CW	Covers	Cover, bag, roll, cap, radome, nacelle, etc.
CX	Cords	Cord with terminals, also composite cables of R.F. and non-R.F. conductors.
CY	Cases	Rigid and semi-rigid structure for housing or carrying equipment.
DT	Detecting Heads	Magnetic pick-up device, search coil, etc.
DY	Dynamotors	Dynamotor power units.
F	Filters	Band-pass, noise, telephone, wave traps, etc.
FN	Furniture	Chairs, desks, tables, etc.
G	Generators (See PU)	Electrical power generators without prime movers.
GO	Goniometers	Goniometers of all types.
GP	Ground Rods	Ground rods, stakes, etc.
H	Head, Hand & Chest Sets	Also includes earphone unit.
HD	Air Conditioning Apparatus	Heating, cooling, dehumidifying, pressure units, vacuum units, etc.
ID	Indicators	Azimuth, plan position, elevation, panoramic, calibrated dials & meters, indicating light, etc.
IL	Insulators	Strain, stand-off, feed-through, etc.
J	Junction Units	Junction, jack & terminal boxes; connector panels, etc.
KY	Keying Devices	Mechanical, electrical and electronic keyers, coders, interrupters, etc.
LC	Line Construction Tools	Includes special apparatus such as cable plows, hoists, etc.
LS	Loudspeakers	Separately housed loudspeakers.
M	Microphones	Radio, telephone, throat, hand, etc.
MD	Modulators	Device for varying amplitude, frequency or phase of alternating current.
MK	Maintenance Kits or Equipments	Radio, telephone, general utility, etc.
ML	Meteorological Apparatus	Barometer, hygrometer, thermometer, scales, etc.
MT	Mountings	Mountings, racks, frames, stands, etc.
MX	Miscellaneous	Equipment not otherwise classified.
O	Oscillators	Master frequency, blocking, multivibrators, etc. For test oscillators see TS.
OA	Operating Assemblies	Operating units mounted together not otherwise covered.
PF	Pole Fittings	Cable hanger, clamp, protectors, etc.
PG	Pigeon Articles	Container, loft, vest, etc.
PH	Photographic Articles	Camera, projector, sensitometer, etc.
PP	Power Supplies	Non-rotating machine type such as vibrator pack, rectifier, thermoelectric, etc.
PT	Plotting Equipments	Except meteorological. Boards, maps, plotting table, etc.
PU	Power Equipments	Rotating power equipment except dynamotors. Electric motors, combustion type engines, etc.
R	Radio & Radar Receivers	Radio or radar receiver, combined unit such as Receiver-Indicator, etc.
RD	Recorders & Reproducers	Tape, facsimile, disc, magnetic, etc.
RE	Relay Assemblies	Electric, electronic, etc.
RF	Radio Frequency Units	Miscellaneous radio frequency apparatus.
RG	Bulk R.F. Cables & Transmission Line	R.F. cable, wave guides, etc., without terminals.
RL	Reel Assemblies	Antenna, field wire, etc.
RP	Rope & Twine	Non-electrical cord, etc.
RR	Reflectors	Target, confusion, etc. Except antenna reflectors. (See AT.)
RT	Receiver and Transmitter	Radio and radar transceivers, transmitter and receiver in one unit, etc.
S	Shelters	House, tent, protective shelter, etc.
SA	Switching Assemblies	Manual, impact, motor driven, pressure operated, etc.
SB	Switchboards	Telephone, fire control, power, panel, etc.
SM	Simulators	Flight, aircraft, target, signal, etc.
SN	Synchronizers	Equipment to coordinate two or more functions.
ST	Straps	Harness, straps, etc.
T	Radio & Radar Transmitters	Communications, range, marker beacon, interrogator, combined Transmitter-Modulator, etc.
TA	Telephone Apparatus	Miscellaneous telephone equipment.
TD	Timing Devices	Mechanical and electronic timing devices, etc.
TF	Transformers	Transformers when used as separate units.
TH	Telegraph Apparatus	Miscellaneous telegraph apparatus.
TK	Tool Kits or Equipments	Miscellaneous tool assemblies.
TL	Tools	All types except line construction.
TN	Tuning Units	Receiver, transmitter, antenna, etc.
TS	Test Equipments	Test and measuring equipment including dummy antenna, pick-up probes, etc.
TT	Teletypewriter & Facsimile Apparatus	Miscellaneous tape, teletype, facsimile equipment, etc.
U	Audio & Power Connectors	Unions, plugs, sockets, adapters, etc.
UG	R.F. Connectors	Unions, plugs, sockets, choke couplings, adapters, elbows, flanges, etc.
V	Vehicles	Carts, dollies, trucks, trailers, etc.
VS	Visual Signaling Equipments	Flag sets, aerial panels, signal lamp equipment, etc.
WD	Two Conductor Cables	Includes non-R.F. wire, cable & cordage in bulk.
WF	Four Conductor Cables	Includes non-R.F. wire, cable & cordage in bulk.
WM	Multiple Conductor Cables	Includes non-R.F. wire, cable & cordage in bulk.
WS	Single Conductor Cables	Includes non-R.F. wire, cable & cordage in bulk.
WT	Three Conductor Cables	Includes non-R.F. wire, cable & cordage in bulk.

Figure 2—Summary of Joint Army-Navy Nomenclature System

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TABLE OF SET OR EQUIPMENT INDICATOR LETTERS

Installation

A—airborne (installed & operated in aircraft)

C—air transportable (designed to be air transportable as stated in specification or military characteristics)

F—ground, fixed

G—ground, general ground use (includes two or more ground installations)

M—ground, mobile (installed as operating unit in a vehicle which has no function other than transporting the equipment)

P—ground, pack or portable (horse or man)

S—shipboard

V—ground, vehicular (installed in vehicle designed for functions other than carrying radio equipment, etc., such as tanks)

T—ground, transportable

U—general utility (includes two or more general installation classes, airborne, shipboard & ground)

Type of Equipment

B—pigeon

C—carrier (wire)

F—photographic

G—telegraph or teletype (wire)

I—interphone & public address

M—meteorological

N—sound

P—radar

R—radio

S—special types (heat, magnetic, etc.) or combination of types

T—telephone (wire)

V—visual and light

X—facsimile or television

Purpose

A—auxiliary assemblies (not complete operating sets)

C—communications (receiving & transmitting)

D—direction finder

G—gun directing

L—searchlight control

M—maintenance and test assemblies (including tools)

N—navigational aids (including altimeters, beacons, compass & instrument landing)

Q—special, or combination of types

R—receiving

S—search &/or detecting

T—transmitting

W—remote control

X—identification & recognition

EXAMPLES OF AN TYPE NUMBERS

Type Number	*Indicates*
AN/FRC-1()	General reference set nomenclature of fixed ground radio communications set No. 1
AN/CRC-3	Air transportable radio communications set No. 3
AN/MPS-2 (XE-1)	Camp Evans Signal Laboratory developmental model No. 1 of ground mobile radar search set No. 2
AN/APS-3-T1	Training set No. 1 for airborne radar search set No. 3
T-78()/SPT-6	General reference component nomenclature for radar transmitter No. 78, part of or used with shipboard radar transmitting set No. 6
R-75/CRW-2A	Radio receiver No. 75, part of or used with air transportable radio remote control set No. 2A
TK-5/FR	Tool kit No. 5 for fixed ground radio equipment, not part of a specific set

NOTES

1. The system indicator "AN" does not mean that both the Army and Navy use the equipment, but simply that the type number was assigned in the AN System.

2. In the AN Nomenclature System, nomenclature consists of a name followed by a type number. The name will be terminology of standard engineering usage. The type number will consist of indicator letters shown on this chart and an assigned number.

3. Modification letters will be assigned for each modification when parts are no longer interchangeable. Different numbers will be assigned to components not electrically and mechanically interchangeable as a whole. The component will retain its original nomenclature even though later made part of other equipment.

4. The type number of an independent major unit, not part of or used with a specific set, will consist of a component indicator, a number, the slant, and such of the set or equipment indicator letters as apply. Example: SB-5/PT would be the type number of a portable telephone switchboard for independent use.

5. *IMPORTANT*: All personnel are cautioned against originating or changing any part of any nomenclature assignment, including modification letters, without authorization.

("AN" System) for Communication and Associated Equipment.

NUMBER | MODIFICATION LETTER

Modification letters will be assigned for each modification not affecting interchangeability of the sets or equipments as a whole, except that in some special cases they will be assigned to indicate functional interchangeability and not necessarily complete electrical and mechanical interchangeability.

The suffix letters X, Y and Z will be used only to designate a set or equipment modified by changing the input voltage, pbase or frequency. X will indicate the first change, Y the second, Z the third, XX the fourth, etc., and these letters will be in addition to other modification letters applicable.

ADDITIONAL INDICATORS

Experimental Sets. In order to identify a set or equipment of an experimental nature with the development organization concerned, the following indicators will be used within the parentheses:

XA — Aircraft Radio Laboratory
XC — Camp Coles Signal Laboratory
XE — Camp Evans Signal Laboratory
XM — Fort Monmouth Signal Laboratory
XN — Navy
XO — Eatontown Signal Laboratory
XP — Army Pictorial Service
XR — NDRC—Division 14
XT — Toms River Signal Laboratory

Example: Radio Set AN/ARC-3() might be assigned for a new airborne radio communication set under development. The cognizant development organization might then assign AN/ARC-3 (XA-1), AN/ARC-3 (XA-2), etc., type numbers to the various sets developed for test. When the set was considered satisfactory for use, the experimental indicator would be dropped and procurement nomenclature AN/ARC-3 would be assigned thereto.

Training Sets: A set or equipment designed for training purposes will be assigned type numbers as follows:

1. A set to train for a specific basic set will be assigned the basic set type number followed by a dash, the letter T, and a number. Example: Radio Training Set AN/ARC-6A-T1 would be the first training set for Radio Set AN/ARC-6A.

2. A set to train for general types of sets will be assigned the usual set indicator letters followed by a dash, the letter T, and a number. Example: Radio Training Set AN/ARC-T1 would be the first training set for general airborne radio communication sets.

Parentheses Indicator. A nomenclature assignment with parentheses, ( ), following the basic type number is made to identify an article generally, when a need exists for a more general identification than that provided by nomenclature assigned to specific designs of the article. Example: AN/GRC-5(), AM-6()/GRC-5, SB-9()/GG. A specific design is identified by the plain basic type number, the basic type number with a suffix letter, or the basic type number with an experimental symbol in parentheses. Examples: AN/GRC-5, AN/GRC-5A, AN/GRC-5 (XC-1), AM-6B/GRC 5, SB-9 (XO-3)/GG.

Modifications After Production. If an article, either a set or a component, is modified after production, the modified article may be identified by the addition of the suffix letter "M" to the original type number. For example, MD-75/GR becomes MD-75M/GR, and AN/ARC-5 becomes AN/ARC-5M. Subsequent modifications for which similar identification is desired will be assigned with a numerical suffix to the M. Subsequent factory productions identical to the modified articles will be identified the same as the modified articles.

NOMENCLATURE POLICY

1. AN Nomenclature will be assigned to:

a. Complete sets of equipment and major components of military design.

b. Groups of articles, of either commercial or military design, which are grouped for a military purpose.

c. Major articles of military design which are not part of or used with a set.

d. Commercial articles when nomenclature will facilitate military identification and/or procedures.

2. AN Nomenclature will not be assigned to:

a. Articles cataloged commercially, except in accordance with Paragraph 1.d.

b. Minor components of military design for which other adequate means of identification are available.

c. Small parts such as capacitors and resistors.

d. Articles having other adequate identification in American War Standard or Joint Army-Navy Specifications.

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CHAPTER II

THEORY OF RADAR

A. Principle of operation.

B. Functional components:

Timer; transmitter; antenna system; receiver; indicator; power supply.

C. Cathode-ray tube:

General; electron beam; fluorescent screen; electrostatic cathode-ray tube; electromagnetic cathode-ray tube.

D. Determination of range:

Time-range relationship; time measurement.

E. Determination of bearing:

Antenna pattern; single-lobe system; double-lobe system.

F. Determination of altitude:

Vertical antenna pattern; estimation from fade chart; measurement of position angle.

G. Types of data presentation:

General; deflection presentations; intensity-modulated presentations.

A. PRINCIPLE OF OPERATION

Radar is an application of radio principles by means of which it is possible to detect the presence of objects, to determine their direction and range, and to recognize their character.

Detection of targets is accomplished by sending out radio waves in a series of pulses from a high-power, ultra-high-frequency radio transmitter. A directional antenna confines these pulses into a beam which is directed over the region to be searched. When the pulse strikes an object in its path, energy is reflected. Some of this echo energy is returned toward the radar, but only a very small portion is intercepted by the antenna. A sensitive receiver connected to the antenna can detect the echo and, therefore, indicate the presence of the object, or target. The determination of the actual range and direction is based on the facts that radio waves travel at the constant velocity of light and that the receiving system can be directional.

B. FUNCTIONAL COMPONENTS

Radar systems now in existence vary greatly as to detail. They may be very simple or, if very accurate data are required, they may be highly complicated. The principles of operation, however, are essentially the same for all systems. Thus a single basic radar system can be visualized in which the functional requirements hold equally well for all specific equipments. In general, the degree of refinement of the circuits used increases with the frequency, since the microwave region lends itself to a higher degree of precision in angular measurement.

The functional breakdown of a radar system resolves itself into six essential components. These are shown in figure 3 and may be summarized as follows:

1. The *timer* (known also as the synchronizer or modulation generator) supplies the synchronizing signals which time the transmitted pulses and the indicator, and which coordinate other associated circuits.

2. The *transmitter* generates the radio-frequency energy in the form of short, powerful pulses.

3. The *antenna system* takes the radio-frequency energy from the transmitter, radiates it in a highly directional beam, receives any returning echoes, and passes these echoes to the receiver.

4. The *receiver* amplifies the weak radio-frequency pulses returned by the target and reproduces them as video pulses to be applied to the indicator.

5. The *indicator* produces a visual indication of the echo pulses in a manner which presents the desired information.

6. The *power-supply* furnishes all a-c and d-c voltages necessary for the operation of the system components.

C. CATHODE-RAY TUBES

1. General.

The cathode-ray tube is a special type of vacuum tube in which electrons emitted from a cathode are accelerated to a very high velocity, are formed into a narrow beam, and are finally allowed to strike a chemically prepared screen which fluoresces, or glows, at the point where the electrons strike. The importance of the cathode-ray tube is that it provides a visual means of displaying and measuring electrical

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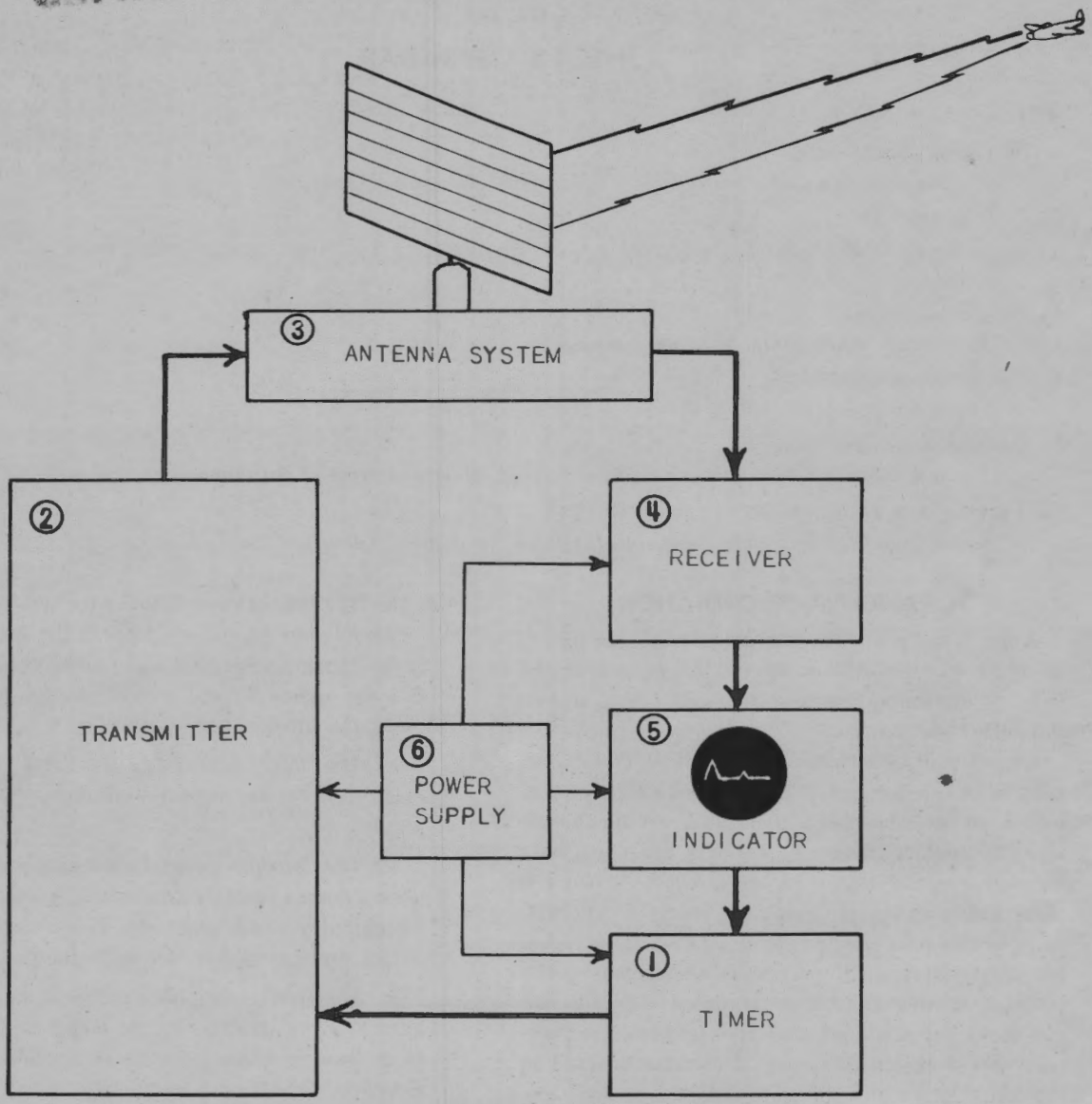

Figure 3—Functional block diagram of radar system.

phenomena. The electron beam can be deflected extremely rapidly because the electrons are so very light in weight that the beam has almost no inertia. This property permits the use of the cathode-ray tube as an instrument for measuring currents and voltages in terms of fractional parts of a microsecond.

The chief use of the cathode-ray tube in radar is as a visual indicating device on which is displayed the information obtained by the radar system. Another important use of this tube is in a test instrument known as an oscilloscope, which permits the examination of all types of electrical waveforms. Since the oscilloscope was in use long before a cathode-ray tube was used as a radar indicator, the name has carried over to the extent that the radar indicator screen is usually called the "scope."

2. Electron Beam.

Electrons are small, negatively charged particles of matter that have negligible weight or mass. All electrons carry the same amount of negative charge and this charge cannot be neutralized or removed.

When a free electron is allowed to enter the space that separates two pieces of metal between which a voltage difference exists, the electron will be attracted toward the positive plate. Thus the stream of electrons that flows in a cathode-ray tube can be moved about by the application of voltages to the deflecting plates in the tube, in much the same way that a stream of water can be moved about by deflecting the nozzle that guides the water. The type of cathode-ray tube in which this sort of control is used is called an *electrostatic* tube.

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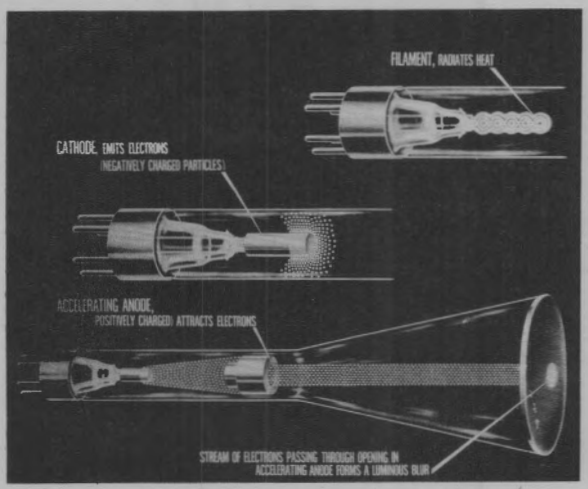
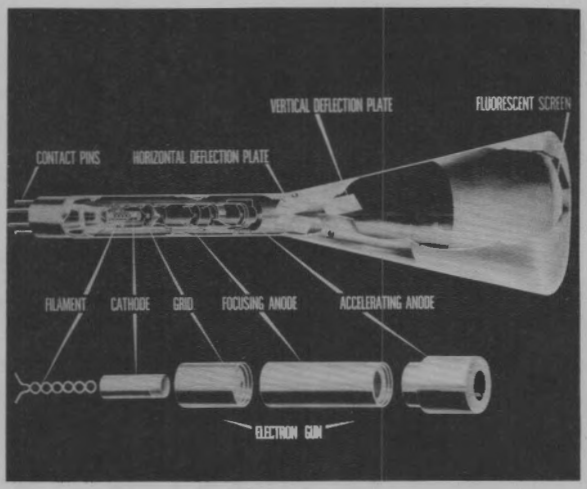
In another type of cathode-ray tube, called an *electromagnetic* tube, the electron beam is controlled by means of magnetic fields. This control is possible because the moving electrons in the beam constitute an electric current. With every electric current there is associated a magnetic field that is capable of interacting with another magnetic field. This interaction produces a force that deflects the electron stream from its normal straight path.

A simplified cathode-ray tube is shown in figure 4A. In this case, the electrons are emitted from the heated cathode, and they proceed in a straight line under the attraction of the accelerating anode. Depending on the strength of this attraction, the velocity of the electrons may reach 10,000 miles per second. Many of the electrons strike the anode and are eliminated, but some of them pass through the small hole in the anode and continue beyond to the screen. However, such a simple arrangement is not able to produce a well-defined spot on the screen. Therefore, cathode-ray tubes which are now in use employ a rather complicated assembly of parts, called an *electron gun,* to produce a sharply focused spot of light (figure 4B). The functions of the electron gun can be explained by comparing it with the optical system shown in figure 5A. A simplified drawing of the electron gun proper is shown in figure 5B. To clarify the analogy between the two drawings, similar parts are labelled with the same letters. The light bulb produces rays which can be formed into a narrow beam and focused to a small bright spot on the screen. The cathode and heater in the vacuum tube produce electrons instead of visible light. A condensing lens at *B* focuses the light rays to a point at *X*, the crossover, and the aperature *C* controls the intensity of the light in the beam. In the cathode-ray tube the control grid exerts similar effects on the electrons. The voltage difference between the grid and cathode produces electric lines of force that act on the electrons in a way that causes them all to pass through the crossover point at *X*. In both the optical and electron systems the function of the remaining elements is to focus an image of the point *X* on the screen at *G*. In the cathode-ray tube the two anodes form an electron lens which serves this purpose. The focus of the spot on the screen in the optical system can be controlled by moving the lenses E and F along the axis of the system. However, it is not practical to move the electrodes within the evacuated cathode-ray tube to focus the electron beam. Therefore, the effective position of the electron lens is varied by changing the voltage applied to the focusing anode at *D*.


FILAMENT, RADIATES HEAT
CATHODE, EMITS ELECTRONS
(NEGATIVELY CHARGED PARTICLES)
ACCELERATING ANODE,
POSITIVELY CHARGED) ATTRACTS ELECTRONS
STREAM OF ELECTRONS PASSING THROUGH OPENING IN
ACCELERATING ANODE FORMS A LUMINOUS BLUR

A. Simplified cathode-ray tube showing function of filament, cathode, and accelerating anode.



B. Exploded view of modern electrostatic cathode-ray tube.

Figure 4—Parts of a cathode-ray tube.

3. Fluorescent Screens.

The fast-moving electrons that flow in the cathode-ray tube possess kinetic energy because of their motion. In order to convert some of this kinetic energy into visible light on the screen, the inside of the tube is coated with a chemical which has the property of emitting light when bombarded with electrons. This property is known as *fluorescence.* Continued emission of light after the bombardment has ceased is called *phosphorescence.*

All *fluorescent* materials *phosphoresce* to some extent, but the duration of this afterglow varies with the material used on the screen. The length of time that the spot will remain visible on the screen, which is called *persistence,* is therefore dependent on the type of fluorescent coating used in the tube. In some cases, short persistence is desired because the screen must show fast variations in signals clearly without the blurring that long afterglow would cause. How-

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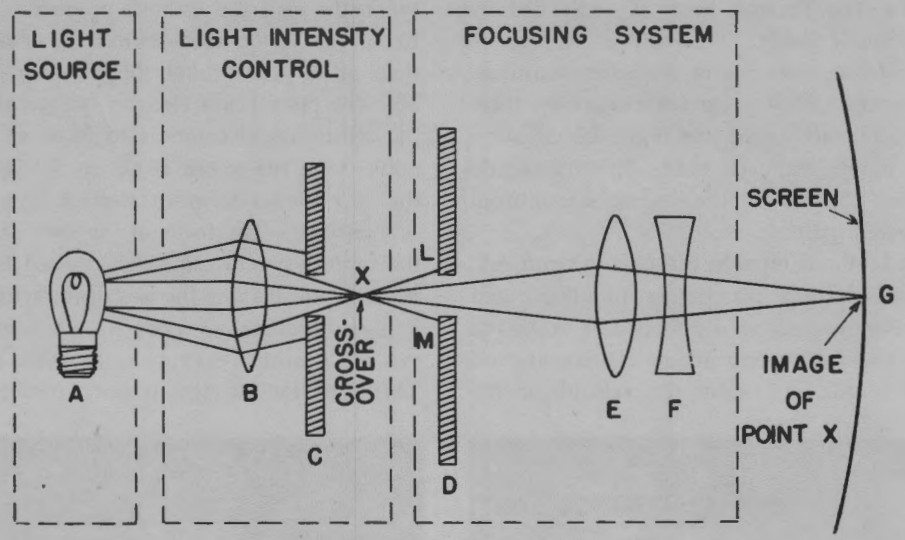
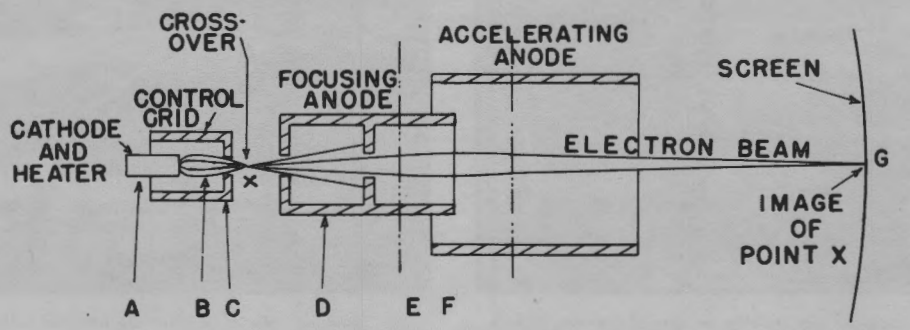


A. Light analogy to electron-beam focusing system.



B. Electrostatic cathode-ray tube focusing elements.

Figure 5—Focus of electron beam.

ever, in many radar indicators the signals are retraced at relatively long intervals. In such cases the screen must be of long persistence so that the pattern fades out slowly, leaving it visible on the screen.

The type of screen material used determines the color of the light emitted. Common colors that are available are green, yellow, blue and white. The screens of short persistent tubes usually are coated with a single chemical layer, but the long persistent tubes often have two distinct chemical coatings on their screens. Usually one layer emits very bright blue light when the electrons strike and this blue light causes the second layer to emit yellow light for several seconds after the electron bombardment is over.

The intensity or brightness of the spot of light that appears on the screen is dependent on the amount of energy that the electrons deliver when they strike. In a given tube, the intensity is controlled by the number of electrons that flow in the beam, which in turn is controlled by the voltage applied to the grid in the electron gun. If desired, the voltage on the grid can be varied so that no electrons can flow, and the screen will be blank. Varying the grid voltage, then, controls the flow of electrons and therefore the intensity of the spot, just as a valve in a pipeline can turn off and on the flow of water.

4. Electrostatic Cathode-Ray Tube.

The electron beam in an electrostatic cathode-ray tube is formed by an electron gun like that shown in figure 4B. It would be very desirable if the only voltage within this gun that affected the focus of the spot were that applied to the focusing anode, but the nature of the electron lens is such that its operation is affected by all the voltages in the tube. Thus, if the grid voltage is changed to vary the intensity of the spot, the position of the crossover point is slightly displaced. In order to compensate for this change, the focus control must be readjusted. The two controls on the cathode-ray tube, then, are not independent. Bset definition can be obtained only by adjusting both the focus and intensity controls alternately. This is

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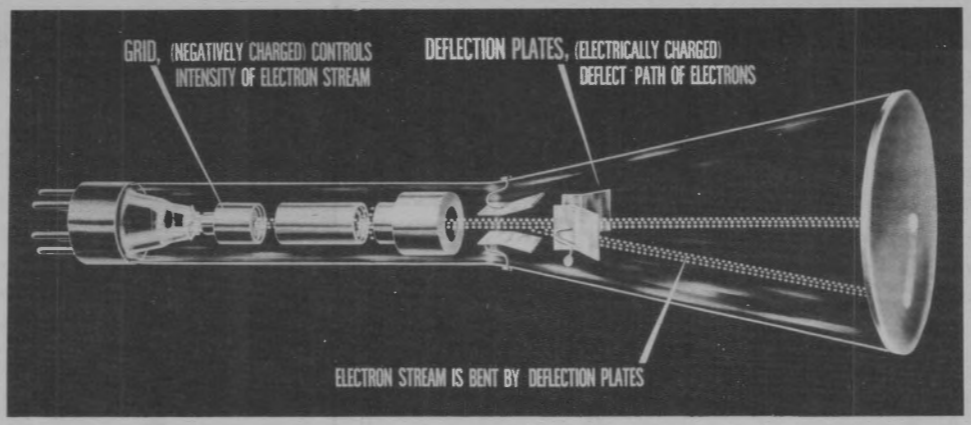

GRID, (NEGATIVELY CHARGED) CONTROLS INTENSITY OF ELECTRON STREAM
DEFLECTION PLATES, (ELECTRICALLY CHARGED) DEFLECT PATH OF ELECTRONS
ELECTRON STREAM IS BENT BY DEFLECTION PLATES

Figure 6—Deflection of electron beam.

not a difficult operation, but it does complicate the apparatus needed to provide large sudden changes in the brightness of the spot on the screen.

If there were no electrodes in the cathode-ray tube beyond the electron gun, the beam would proceed straight toward the screen and would make a single bright spot in its center. The usefulness of the cathode-ray tube lies in the fact that the beam can be deflected to any part of the screen. The deflection is caused by the voltages applied to the deflection plates shown in figure 6. One pair of these plates controls motion in the horizontal direction and the other controls motion in the vertical. Combinations of voltages applied to these two pairs of plates can produce patterns of all sorts—even a picture when the tube is used as a kinescope in a television receiver.

The human eye retains an image for about 1/16 second after viewing. Motion pictures make use of this characteristic of the human eye in creating the illusion of motion by a series of still pictures flashed on the screen so rapidly that the eye cannot follow them as separate pictures. In a cathode-ray tube the spot can be moved so quickly that a series of adjacent spots can be made to appear as a line, if the beam is swept over the same path fast enough. As long as the electron beam strikes in a given place at least 16 times a second, the spot will appear to the human eye as a source of continuous light, but the light will flicker. If each spot is illuminated more often than about 40 times per second, even the flicker will not be apparent, and a uniform luminous line will show on the screen.

5. Electromagnetic Cathode-Ray Tube.

The electron gun in the electromagnetic cathode-ray tube is somewhat different than that in an electrostatic tube. The difference lies in the use of a steady magnetic field as an electron lens instead of the charged electrodes. (See fig. 7.) Control of the brightness of the spot is the same in both types of tubes. An advantage that results from magnetic focusing is that the brightness and focus are much less interdependent than in the electrostatic tube. It is primarily for this reason that the designers sometimes use electromagnetic tubes and sometimes electrostatic, depending on the type of pattern which it is desired to produce on the screen.

However, even in the electromagnetic tube too great a change in grid voltage will affect the focus. If too strong a signal is applied to the grid, the spot becomes very bright and badly defocused. This phenomenon has been termed "blooming" since maladjustment of

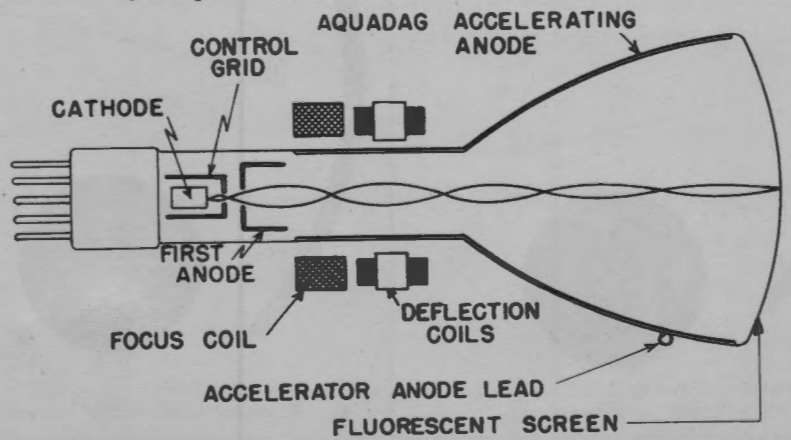


Figure 7—Electromagnetic cathode-ray tube.

this sort causes the normally small spot to bloom into a large blob. The circuits of radar indicators usually are designed to minimize this undesirable effect.

In an electromagnetic tube the beam is deflected by a varying magnetic field. In many cases the deflecting coils are mounted in a yoke that can rotate around the neck of the tube, which is of advantage when a rotating radial sweep is desired.

D. DETERMINATION OF RANGE

1. Time-Range Relationship.

A radar pulse, once it has been radiated into space, continues to travel at a constant velocity. When it strikes a reflecting object, there is no loss in time, but only a redirecting of the energy. Its velocity is that of light, which is approximately 162,000 nautical

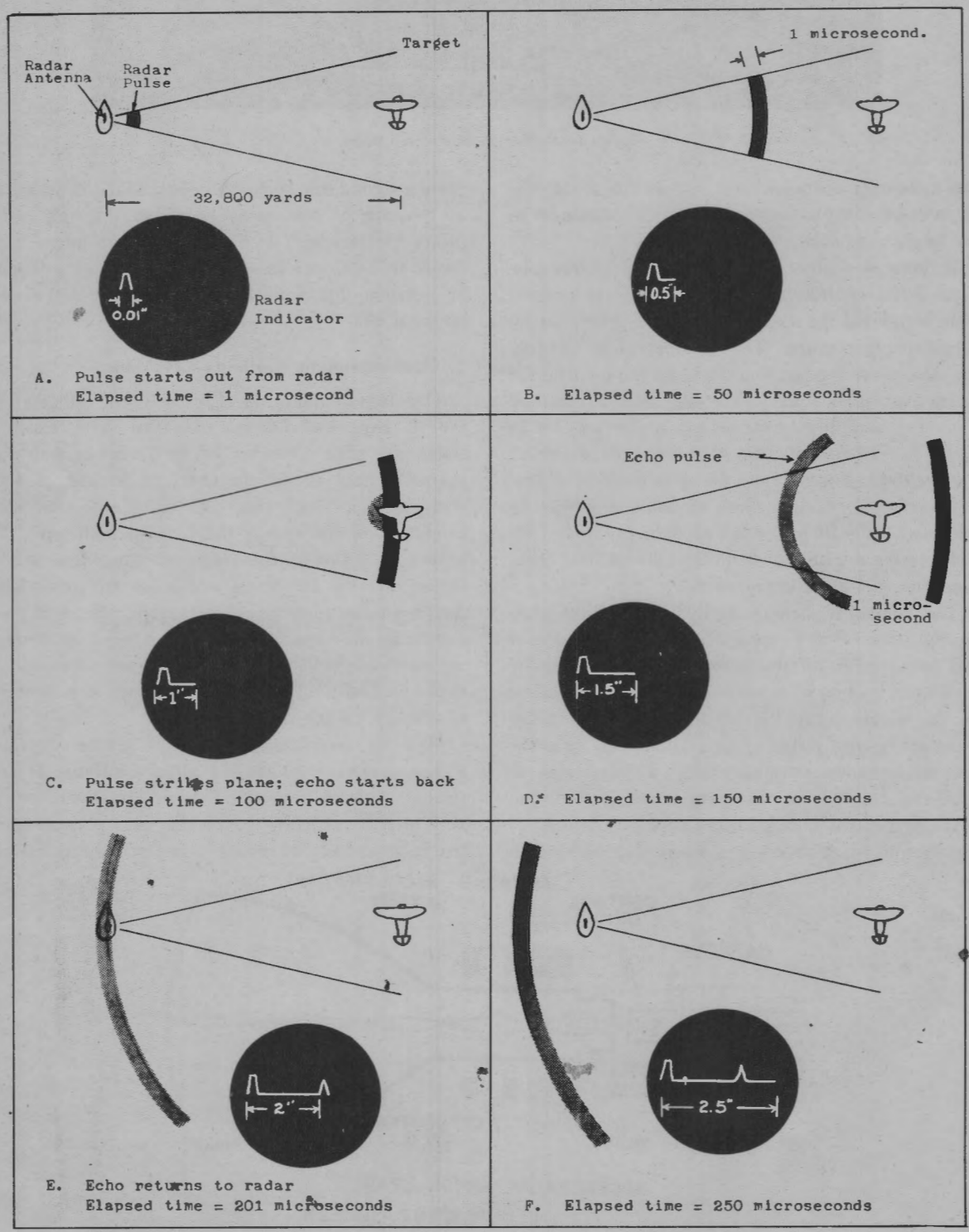


Figure 8—Principle of echo ranging.

miles per second or, more accurately, 328 yards per microsecond.

The constant velocity of propagation of the radio frequency energy is used in radar to determine range by measuring the *time* required for a pulse to travel to the target and to return. For example, assume that a pulse of one microsecond duration is transmitted toward an airplane which is 32,800 yards away. In figure 8A the pulse is shown as it just starts from the radar antenna toward the target. The pulse is midway between the radar and the plane in *B*, and in *C* it has traversed the 32,800 yard distance at a speed of 328 yards per microsecond. Therefore, 100 microseconds have elapsed. As soon as the leading edge of the pulse strikes the plane a small part of the energy is reflected. Since the transmitted pulse is one microsecond in duration, the reflected pulse is also one microsecond in duration because energy is reflected from the plane continually during the one microsecond interval in which the transmitted energy strikes the plane. In D the echo pulse is shown returning toward the radar while the transmitted pulse continues beyond the target. The time required for the echo to travel from the plane to the radar is 100 microseconds, since the return trip is also 32,800 yards long. Figure 8E shows the echo pulse returned to the radar system. The total elapsed time is 200 microseconds for a distance traveled of twice the actual range of the target. For radar ranging, therefore, the velocity of propagation of r-f energy may be considered to be one-half of the velocity of light, or 164 yards per microsecond. In the example of figure 8,

$$\text{Range} = 164 \times \text{time, or}$$
$$\text{Range} = 164 \text{ yards } /\mu\text{sec} \times 200\ \mu\text{sec} = 32{,}800 \text{ yards}$$

2. Time Measurement.

In order to employ this time-range relationship, the radar must have a time-measuring device. In addition, since there may be more than one target in the region under search, some means of separating the echo signals must be included. The cathode-ray tube is well suited to such a task, since the information can be displayed visually on a time scale which can be produced readily on the face of the tube.

As an example of the measurement of time with a cathode-ray tube assume that a horizontal linear sweep is used to move the beam across the screen at a velocity of 1 inch per 100 microseconds. The echo signals received from a target at a range of 32,800 yards are applied to the tube to cause vertical deflection of the beam. The appearance of the cathode-ray tube at several instants is shown in figure 8. In A the trace have moved 0.01 inch across the screen, and the transmitted pulse has just left the antenna. The transmitted pulse is shown on the screen as a vertical deflection since a small part of the transmitted energy leaks directly into the receiver. After 100 microseconds have elapsed, the pulse reaches the target 32,800 yards away, and the spot has moved 1 inch across the screen (fig. 8*C*). Since the radio-frequency energy is out at the target, there is no vertical deflection of the trace at this instant. The reflected pulse returns to the radar anenna at the end of 200 microseconds, during which the sweep trace has moved a total distance of 2 inches. For the duration of the received pulse, one microsecond, the trace is deflected vertically (fig. 8E) and the indication of the target appears as a vertical deflection two inches from the start of the trace. Thus, with a constant sweep velocity of 1 inch per 100 microseconds, a time scale is produced which is equivalent to 100 μsec $\times$ 164 yards per μsec = 16,400 yards per inch of trace. As a result, the range of any echo that appears on this time base can be scaled off directly in yards without the necessity of first measuring the time, and then converting to range.

The single trace illustration used will not persist on the cathode-ray tube screen long enough to be useful. Therefore, it is necessary to repeat the sweep and pulse transmission periodically. If the two operations are always made to start in the same time relation, the signals returned from a given target will be superimposed on successive traces, so that a steady bright line will be visible on the screen.

E. DETERMINATION OF BEARING

1. Antenna Pattern.

Radar antennas are made directional in order to produce a single narrow beam in one direction. This narrow beam, or lobe, permits maximum energy to be sent in any desired direction. A plot of the signal strength at a given point versus the angular position of the radar antenna is called the radiation pattern of the antenna. In addition to transmitting maximum energy in a desired direction, a directional antenna also receives energy most effectively from that same direction. To obtain an approximate pattern of an antenna, the amplitude of the echo signal from a fixed target can be plotted versus the angular position of the antenna.

2. Single-Lobe System.

The antennas of most radars are designed so that they radiate energy in one lobe that can be moved only by moving the whole antenna. The general shape of such a single lobe is shown in figure 9. The teardrop outline illustrated may be said to represent a polar plot of echo amplitude versus bearing. Thus, for a particular target at a particular range, the echo amplitude at any bearing relative to the lobe axis may be found by drawing a line along that bearing from the antenna position at point *A*. The length of the

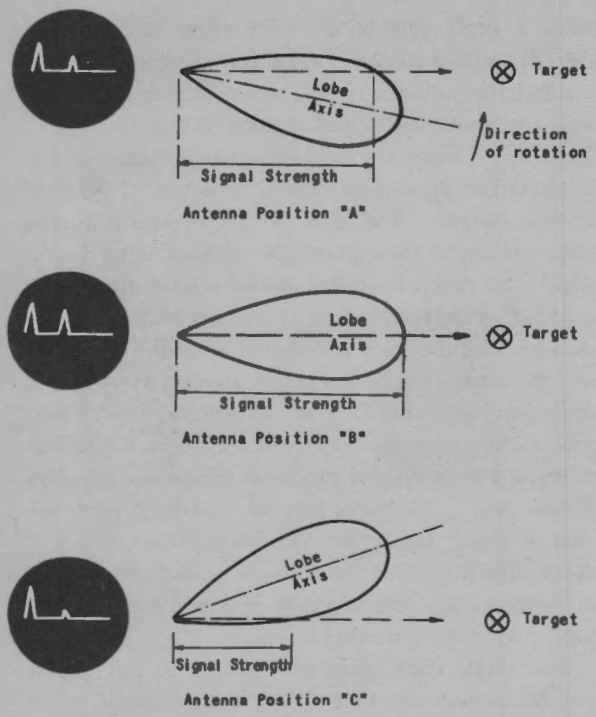


Figure 9—Relationship between lobe axis and target bearing.

line between *A* and the intersection with the lobe outline indicates echo amplitude. For other targets and targets at different ranges, other lobe contours must be drawn if echo amplitude is to be represented. However, all these lobes are similar in shape, so that they would form a family of curves like the striations on an oyster or clam shell.

As the antenna rotates, then, the echo signal varies in amplitude. At antenna position *A* or *C* the echo is relatively small, but at position *B*, where the lobe axis is pointed directly at the target, the echo is maximum. The bearing of the target can be obtained by training the antenna to the position in which the echo size is greatest.

3. Double-Lobe System.

The shape of an antenna lobe is such that the echo signal strength varies more rapidly with change of bearing on the sides of the lobe than near the axis. One common system of using this rapid variation of signal strength employs an antenna capable of producing two identical lobes whose axes are displaced by some angular distance (fig. 10). The two lobes intersect at only one point, known as the crossover point, at which each lobe receives equal echo signals from a target on the line of bearing through the crossover point.

When the target is in position *A*, the echo signal strength received by lobe 1 is proportional to *Y*, and that received by lobe 2 is proportional to *X*. The indicator used with this type of system shows the echoes from the two lobes separately. Thus, when the target is at *A* the right-hand pip is smaller than the left, so that the operator knows to train left to bring the antenna axis on target. If the antenna were rotated so that the target is in position *B*, the signals received by the two lobes are reversed, and the indicator appearance is therefore reversed too. At position *C*, the signals received by the two lobes are equal and proportional to *Z*. The fact that the two pips on the indicator are of the same height is an indication that the antenna axis is on the bearing of the target.

The use of two lobes instead of a single lobe greatly increases the precision of bearing measurement because the operator has a more sensitive indicator to show whether he is off target or not. In addition to the increased accuracy possible with this system, it has the advantage of providing the operator with a sense of direction. If the antenna is off target to the right, as at *A* in figure 10, the inequality of the pips on the scope shows the direction to train to get back on, and the amount of inequality in echo height is an indication of how far off target the antenna is trained. However, these advantages are obtained at the expense of considerable complexity and a loss in the maximum range of the radar when the antenna is kept on target.

F. DETERMINATION OF ALTITUDE

1. Vertical Antenna Pattern.

If the radar antenna can be elevated sufficiently that none of the radiated energy strikes the surface of the water, the pattern of the radiation in a vertical plane will be a smooth lobe, similar to that shown in figure 9. However, if some of the radiated energy strikes the sea, the radiation pattern is considerably modified. This modification results from interference between the energy that is radiated directly toward the target and energy that reaches the target after reflection from the water. The effect of this interference is to break up the single lobe into a number of smaller lobes separated by areas called nulls, in which no echoes can be obtained. A three-dimensional sketch of the area

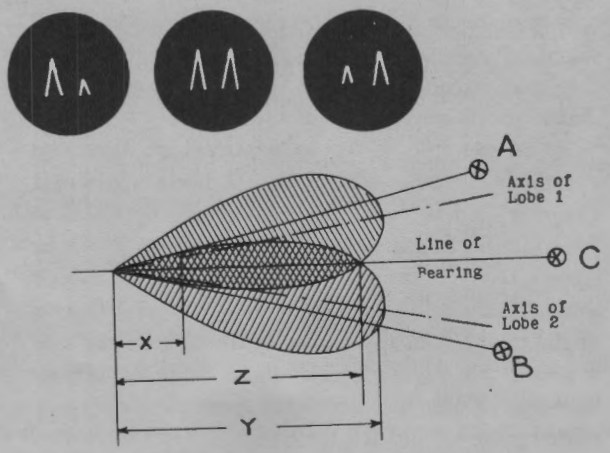


Figure 10—Double lobe pattern.

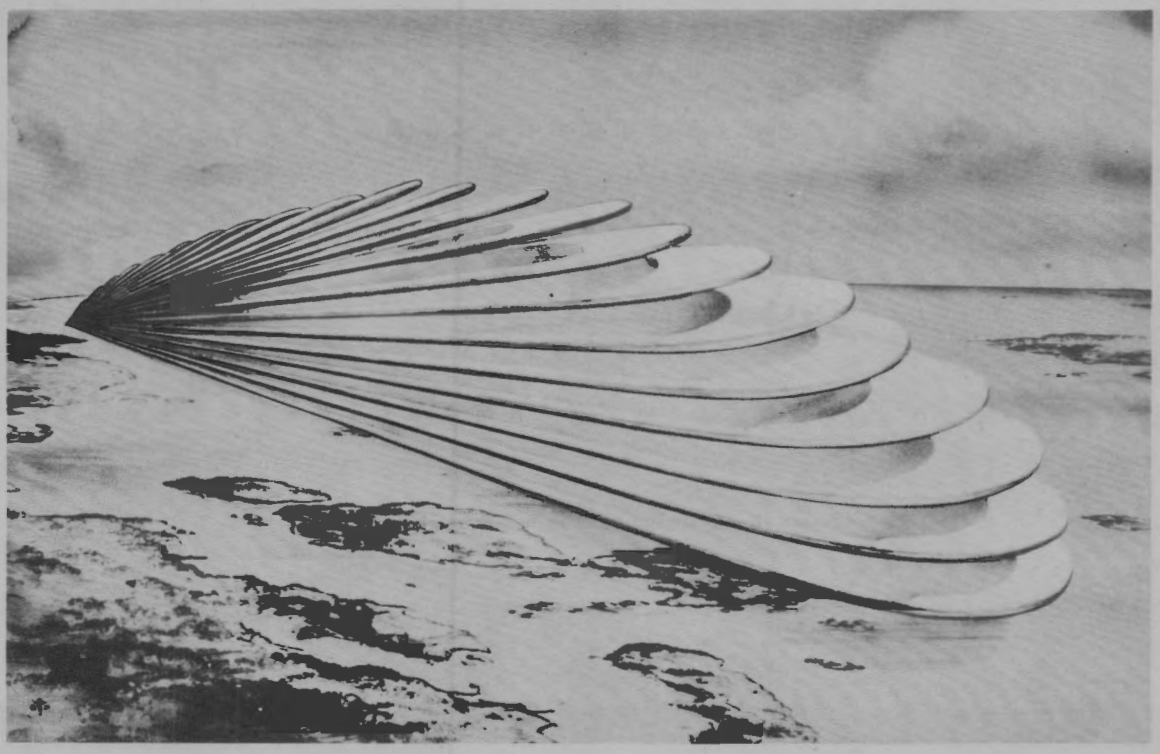


Figure 11—Typical vertical coverage pattern produced by water reflection.

"illuminated" by pulses transmitted from an SK antenna is shown in figure 11.

2. Altitude Estimation from Fade Chart.

The positions of the lobes and nulls in an antenna pattern remain the same as long as the antenna height and the radar frequency are unchanged. Therefore, it is possible for a chart showing the positions of the lobes and nulls to be prepared as a means of aiding in the estimation of altitude of aircraft targets. To use such a chart, called a fade chart, the radar operator must notice the ranges at which the plane disappears in the null areas, and by applying these ranges to the chart, an estimate of altitude can be made. Since the positions of the nulls depend only on the geometry of the situation, the fade chart can be calculated, and in fact a circular calculating device has been made up which eliminates the need for plotting the chart. For most dependable results, however, the data should be determined experimentally by flying an aircraft at several constant altitudes and recording both the observed signal strengths and the ranges.

Altitude can also be estimated by noting the range at which the echo is first detected. At least the bottom of the lowest lobe must be plotted to make such a method practical. This curve should be derived from actual measurements to reduce possible errors. However, this method is not very reliable, even with an experimentally obtained curve because too many variables beyond the control of the operator affect the range at which a target is first detected.

3. Measurement of Position Angle.

If the antenna beam can be elevated, the position angle of an aircraft can be determined by the same processes that are used to measure bearing, as long as the antenna is so designed that none of the radiated energy strikes the sea. Usually the position angle is measured by an antenna in which some form of double lobing or beam scanning is used. Special indicators are often used with radars capable of height finding in order to facilitate the determination of altitude from the measurement of position angle. The range measured by the radar on an aircraft is called the slant range (fig. 12). When both the position angle and the slant range are determined, the altitude of the plane can be found by solving the triangle *RTA* in figure 12 by calculation, by reference to a graph, or by a simple computer that is built into some radars. Altitude found in this way is not the true height of the airplane above the earth because the calculation is based on the assumption that the earth is flat. Thus in figure 12, it is assumed that the surface of the earth is the plane RA in which the ship seems to be sailing. As a result, the indicated altitude is *TA*. Because of the curvature of the earth, the actual altitude of the aircraft is *TB* rather than *TA*. At a range of 50 miles, the difference in these two altitudes may be as much as 1,500 feet.

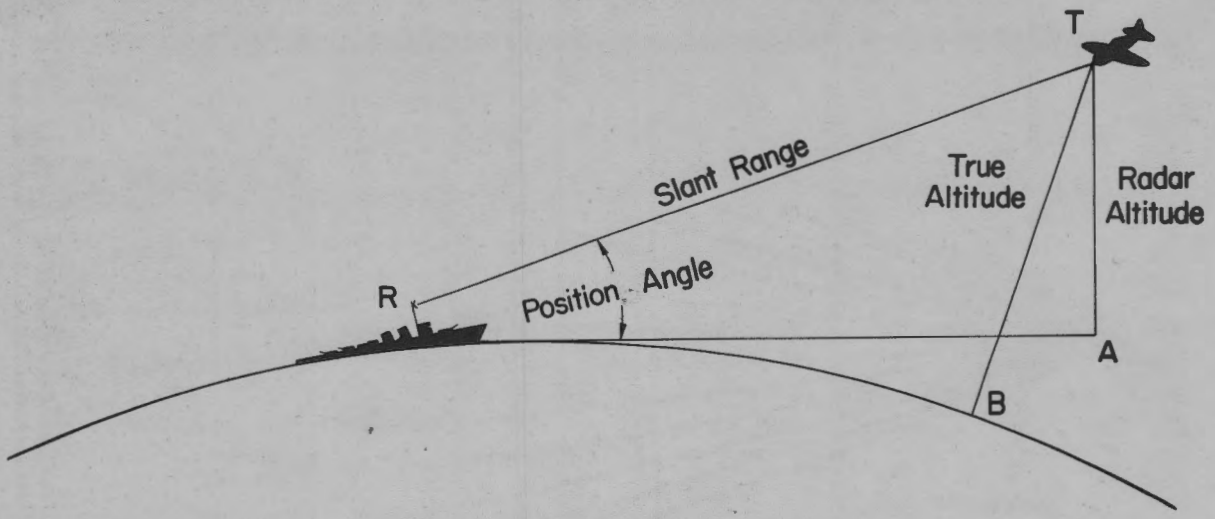


Figure 12—Determination of altitude from position angle.

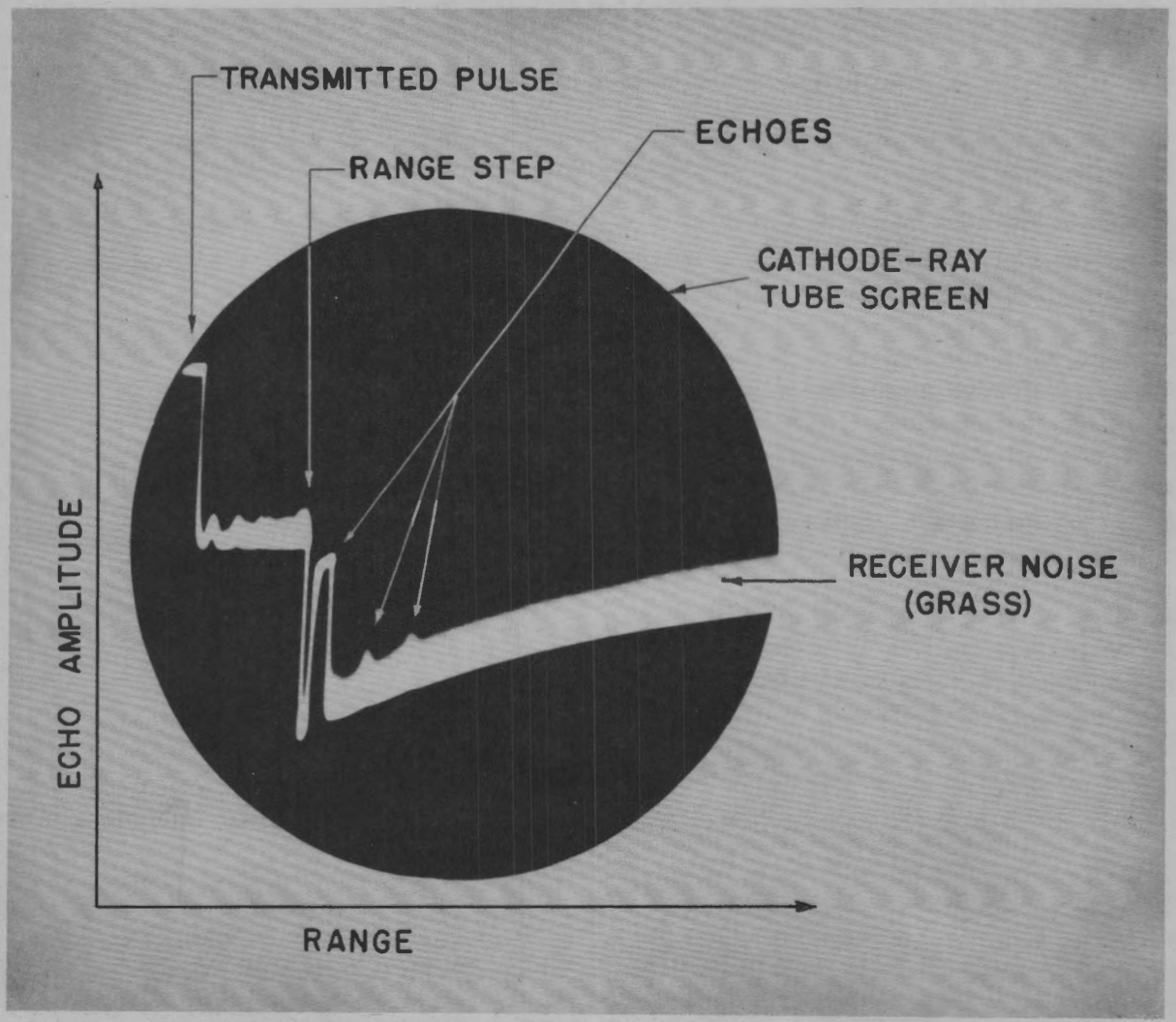


Figure 13—Type A presentation with range step (Type M scan).

G. TYPES OF DATA PRESENTATION

1. General.

The data obtained by radar is almost always displayed on the screen of a cathode-ray tube in order to enable the operator to interpret the received echoes. In some cases meters may be used to show some particular quantity, but meters have the disadvantage of reacting rather slowly to variations in the echo signal and there is no direct indication of when the meter is influenced by signals returned from more than one target. Thus, the utility of a meter as a radar indicator is rather severely limited. Cathode-ray tubes, on the other hand, are well able to display simultaneously the echoes from many targets and the inertia in this device is so small that variations that occur in less than a millionth of a second can be readily displayed.

There are two general methods of display in use with cathode-ray tubes at present. In one, the echo shows as a deflection, or pip, in a bright line. The position of this pip along the line is an indication of the range of the target. In the other general type of indicator the echoes show as bright spots on an otherwise dark screen. These two types of indicators are termed deflection and intensity modulated, respectively.

2. Deflection Presentations.

The most common kind of deflection indicator is the type A scope, shown in figure 13. The time base is produced by a linear rise in voltage which causes horizontal deflection of the spot across the cathode-

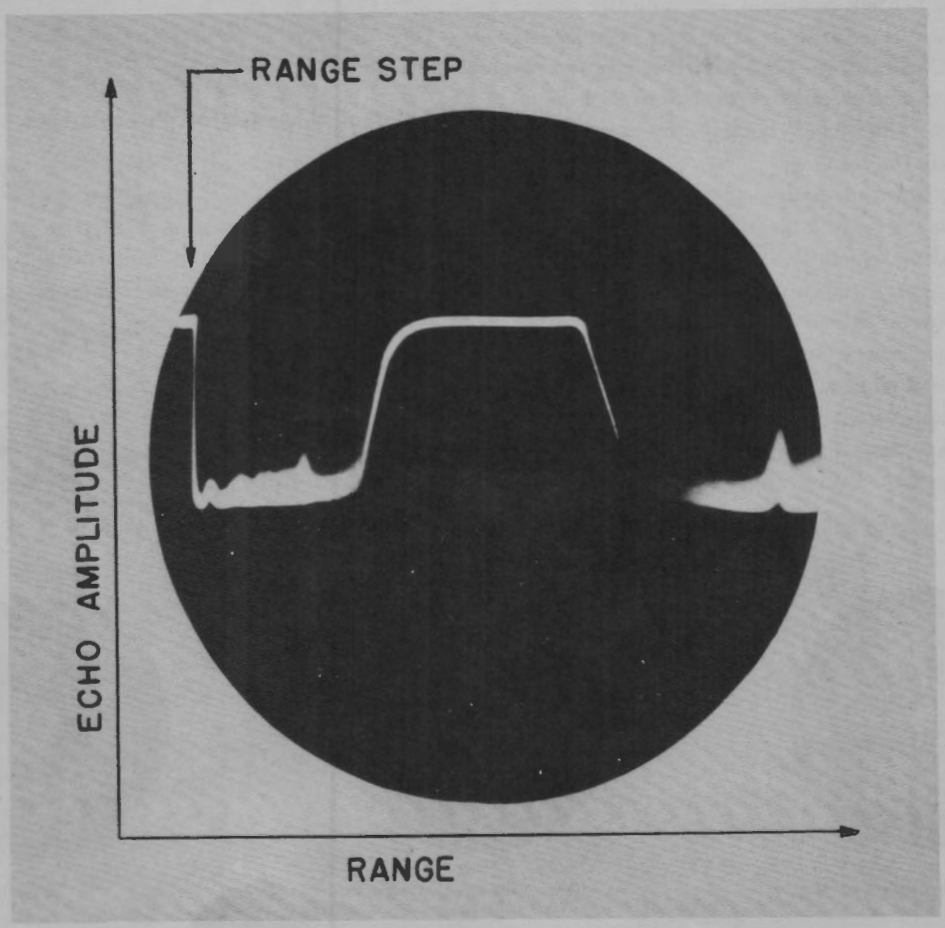


Figure 14—Type R presentation provided in modernized SG.

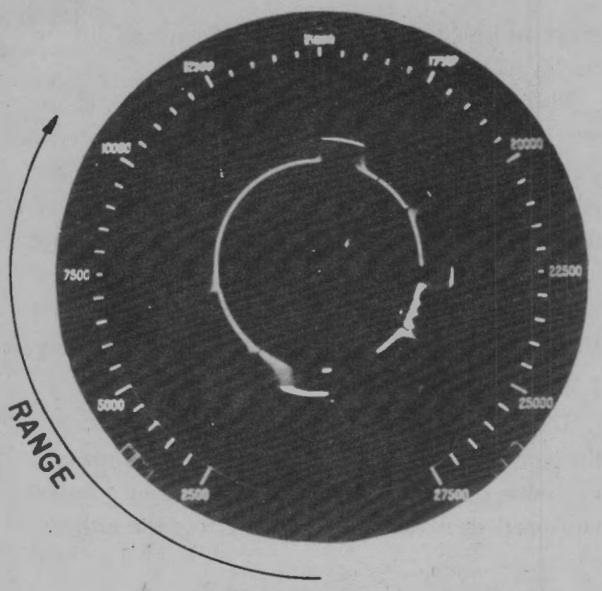


Figure 15—Type J presentation.

ray tube screen. The echo signal output of the receiver causes vertical deflection of the trace. A calibrated scale may be placed over the screen to permit reading range directly because there is a linear relationship between the sweep and time. In many radar sets, however, a marker produced electronically makes a sharp break in the time base as in figure 13. By aligning this marker with the echo signal, or pip, the range of the target can be read directly from range counters geared to the knob which controls the position of the marker along the trace.

In many types of equipment it is also possible to select a small sector of the time base near the range marker and to expand this part of the trace to the full width of the screen. Usually the length of this expanded sweep, which is also called a type R scope or a precision sweep, is 2,000 to 5,000 yards. The R scope shown in figure 14 is the one provided in the modernization of the SG radar. In this case the expansion takes place from the range to which the step is set. The step always appears at the extreme left of the screen, and the trace is approximately 5,000 yards long across the full width of the screen. Notice that on this type of presentation the echo is spread out so that its character can be observed more easily than on the normal sweep. The expanded type of presentation is advantageous not only because range can be read with greater precision than on the full sweep, but also because range resolution is improved and the reading of IFF responses is facilitated.

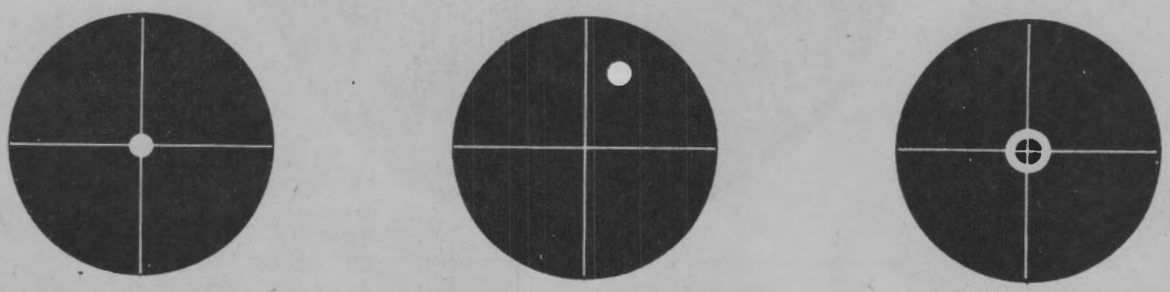
In a few indicators a circular time base is used because the trace can be made almost three times the length of the straight trace on a given cathode-ray tube. An indicator in which a circular time base is used is called a Type J scope (fig. 15A). The echoes on this type of scan appear as radial deflections, and range is measured around the circumference of the circle. In the Mark 26 scope, illustrated in figure 15, zero range is at 6 o'clock.

Another type of indication shows only a single selected echo as a bright spot on a screen over which crosshairs are placed (fig. 16). This type of presentation is similar to that of a telescope. The antenna beam is kept on target by the pointer holding the spot on the horizontal line and the trainer holding the spot on the vertical line. When the target is lost, the solid bright dot opens into a circle, as shown in figure 16C. This type of indicator is used on some antiaircraft fire control radars.

3. Intensity-Modulated Presentations.

In order to present both range and bearing data on the same screen, echo signals are made to appear as bright spots. By this means, the position of the bright spot in one dimension indicates range, while the position in the other dimension indicates bearing. When no echo signals are applied to an indicator of this sort, the screen is dark.

The type B presentation shows range vertically versus bearing horizontally (fig. 17). The bearing indicated by the vertical center line on the screen corresponds to the optical axis of the antenna and the



A. Antenna beam on target.

B. Antenna beam below and to left of target.

C. Target lost.

Figure 16—Moving spot indicator.

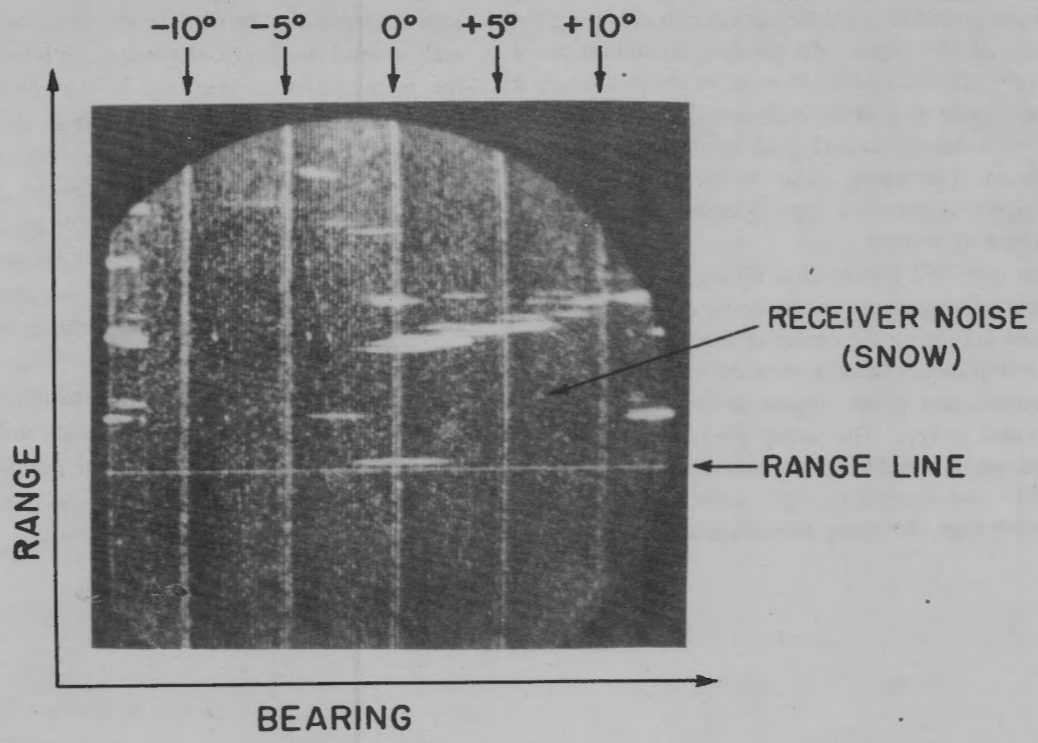


Figure 17—Type B presentation.

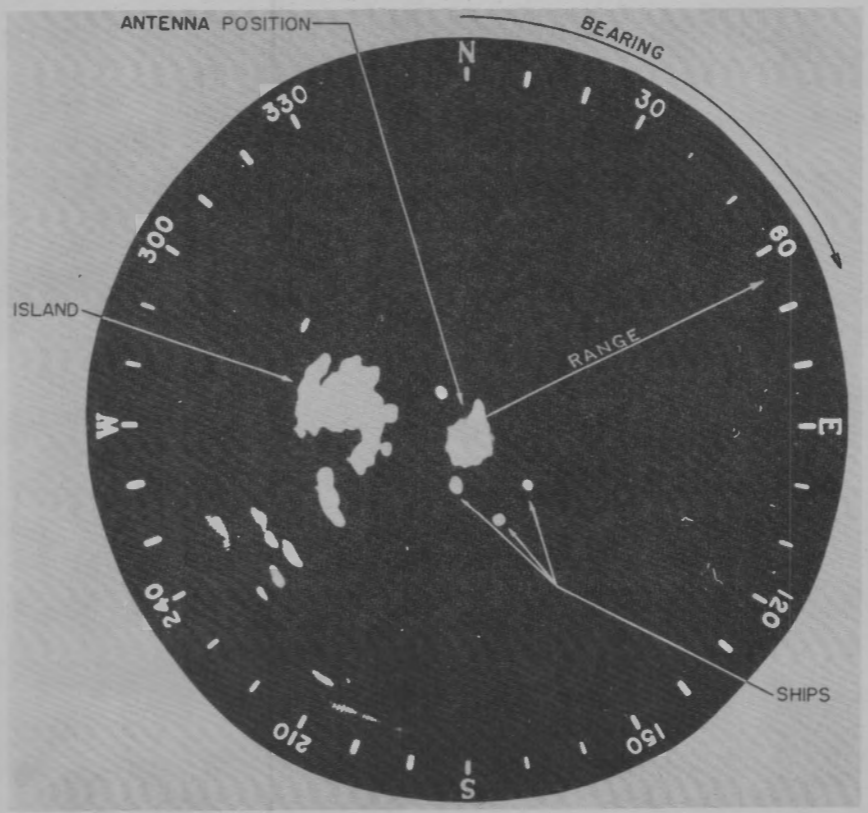


Figure 18—Type PPI presentation.

director on which the antenna is mounted. Bearing lines are provided to aid the operator in obtaining the bearing of the target. To produce an indication of this type, the antenna beam must be swept through a limited angle at a fairly high speed. Although this type of scanning is analogous to the scanning of a television iconoscope, radar is not yet sufficiently developed to permit a type B scan to indicate the silhouette of a target.

The type PPI presentation shows, in polar coordinates, a radar map of the area being covered, with the antenna occupying the center of the screen (fig. 18). The sweep moves radially outward from the center of the screen, and echoes appear as bright spots along this radial sweep. The sweep position is controlled by and synchronized with the antenna position throughout 360° rotation. For example, if the antenna is pointing 000° true, the sweep trace moves from the center of the screen to the top. Either true or relative bearings of targets may be read directly from the calibrated scale around the screen, depending on whether or not the gyrocompass is connected in the system. Range is indicated by the radial distance from the center of the screen at which the echo appears. Thus range may be estimated from a series of concentric circles that may be put on a transparent overlay or produced electronically on the screen. Range may be measured by the use of a range marker which appears on the screen as a circle called a range ring, whose diameter is controlled by the range knob.

Other types of indicators have been developed and are in use. The types discussed here are fundamental, and other kinds of presentation that may be encountered will probably be related basically, but improved to present the data in a more useful way.

CHAPTER III

CAPABILITIES OF RADAR

A. Introduction:

Classes of equipment; requirements of a radar.

B. Applications of radar and associated equipment:

Air search; height-finding and low-angle search; surface search; equipment for submarines; fire control; repeater PPI; recognition equipment; radar beacons.

C. Interpretation of echoes:

General; characteristics of pips; type of indicator.

D. Characteristics of shipborne radar:

Radar installations in ships; performance and operational data; operating console photographs.

A. INTRODUCTION

Radar equipment is capable of detecting the presence of objects in the air and on the surface and of measuring their range and bearing. Some of the sets that have been produced are capable of measuring directly the position angle of aircraft, while others permit an estimate of elevation to be made by reference to a calibration chart.

Three general classes of radar equipment have been developed:

(1) Search or detecting equipment.
(2) Fire control equipment.
(3) Recognition and beacon equipment.

Each of these classes can be subdivided into several types of equipment that have been produced to perform well one function. For example, search equipment is available for air search, height-finding and low-angle search, and surface search. Radar equipment for submarines is primarily detecting equipment, but the surface search radar is capable of determining range and bearing accurately enough to control torpedo fire. Since submarine radar is designed for a specialized application, it will be considered separately from other search equipment.

Fire control radar, which is capable of a rather high order of accuracy, has been developed for use with all types of gun batteries. If the required accuracy cannot be obtained by radar alone, the equipment may be used for the control of searchlights to permit optical control of gunfire. The Navy has no radar equipment built specifically for searchlight control, but it is reported that the Japs are using radar designed for this purpose.

Since radar equipment alone is not capable of distinguishing friendly from enemy vessels, auxiliary equipment has been produced to aid in this vital function. This equipment is called IFF, which stands for "Identification, Friend or Foe." A similar type of accessory equipment is the radar beacon or "Racon."

In many cases the uses of a given search radar can be extended if the indication of the echoes can be displayed simultaneously in several locations. To permit this kind of operation, several types of repeater plan position indicators (RPPI) have been produced.

The requirements of each of the several types of radar differ widely. An air search radar must measure range and bearing to only a fair degree of precision since its primary function is warning of the presence of aircraft at extreme ranges. Radar used for aircraft control should be capable of determining range, bearing, and altitude with good accuracy, and it must be capable of resolving targets that are close together in order to control successfully the intercepting planes. Air search radar is used in conjunction with the height-finding and low-angle search radar for the control of aircraft. Surface search radar must determine range and bearing of targets on the surface with moderate precision, and must have sufficiently high resolution to enable ships within firing range to show as separate targets on the radar indicator so that targets can be indicated to fire control radars. Fire control radar must determine range, bearing, and altitude with the greatest precision practical in order to produce accurate gunfire, and the radar should be capable of resolving two very close targets so that shell splashes can be distinguished from the target proper, allowing the guns to be spotted on to the target.

As a result of these varying requirements, the several types of radar equipment have fundamentally different characteristics which allow them to perform their *primary* functions best, generally at the expense of other functions. Thus, in present air search radar, some sacrifice is made of effective range at low altitudes and degree of resolution between targets in order to enable the set to detect aircraft at very long ranges. Surface search radar is able to detect both vessels on the surface of the ocean and low flying planes, but it is unable to detect aircraft at high altitudes.

B. APPLICATIONS OF RADAR AND ASSOCIATED EQUIPMENT

Although each radar equipment is designed for one primary function, the uses to which sets may be put overlap to some extent. Listed below are many of the applications of radar equipment. Other applications will undoubtedly be found as more operating experience is gained and as newer sets with enhanced capabilities become available in the Fleet.

1. Air search radar equipment.—Navy types: SA, SC, SK, SR, SX.

(*a*) Warns of approaching aircraft before they can be sighted visually, so that:

(1) The direction from which attack may develop may be indicated.

(2) Fighters may be flown off in time if an air attack is imminent and a carrier is in company.

(3) A fighter escort may be called for in sufficient time if no carrier is in company.

(4) AA defenses may be brought to the proper degree of readiness in sufficient time.

(*b*) Allows the constant observation of the movements of enemy aircraft, once detected, and the direction of own fighter planes to a position suitable for interception.

(*c*) Warns of the presence of enemy surface craft that are beyond the visible range at night or during conditions of poor visibility, so that correct disposition of the fleet may be made to meet an attack, or preparations made to attack the enemy by surprise. It must be remembered that this is the primary function of the surface search radar.

(*d*) Provides security against night attack, attacks during conditions of poor visibility, or from behind a smoke screen.

(*e*) Scouting.

(*f*) Ranges on land up to 150 to 250 miles.

(*g*) Obtains bearings, but not ranges, on other ships having radar on the same frequency at distances in excess of the maximum ranges from which echoes can be received. This ability is of especial value in making a rendezvous with a convoy.

2. Height-finding and low-angle search radar equipment. Navy Types: SM, SP, SX.

(*a*) Obtains accurate range, bearing, and altitude data on enemy planes to assist in the direction of own fighter planes to a position suitable for interception.

(*b*) Permits continuous control of own fighter planes while they are within range of the radar.

(*c*) Detects low-flying aircraft.

(*d*) Acts as high-power surface-search radar when no air attack is imminent.

(*e*) Obtains meteorological data by observing the movements of balloons equipped with radar reflectors. The ability of the height-finding and low-angle search radar to measure position angle as well as range and bearing allows it to provide a more useful track on the balloon than can be obtained with an air-search radar.

(*f*) Detects the presence and extent of thunderstorms and other severe weather disturbances. This enables aircraft carriers to maneuver to the most favorable area for launching or receiving planes, and to vector planes around the storm area.

(*g*) Ranges on distant land up to 80 miles.

3. Surface search radar equipment. Navy Types: SF, SG, SL, SN, SO, SQ, SU.

(*a*) Warns of the presence of enemy surface craft that are beyond the visible range at night or during conditions of poor visibility so that the correct disposition of the Fleet may be made to meet an attack, or preparations made to attack the enemy by surprise. Radar will not detect ships beyond visible range on clear days.

(*b*) Coaches fire control radar to enable it to get on target quickly.

(*c*) Provides security against attack at night, during conditions of poor visibility, or from behind a smoke screen.

(*d*) Scouting.

(*e*) Obtains range and bearing on prominent landmarks and buoys as an aid to piloting, especially at night and in conditions of poor visibility.

(*f*) Facilitates station keeping, especially at night and in poor visibility.

(*g*) Acts as auxiliary fire control radar in conjunction with a precision PPI.

(*h*) Indicates spots on shell splashes in both range and bearing, especially in ships that are not equipped with a fire control radar such as the Mark 8.

(*i*) Detects life boats and life rafts at short ranges when they are equipped with corner reflectors. There is some indication that floating objects, wreckage, and even men in the water can be detected at short ranges, so that surface search radar may be used to some extent in rescue operations.

(*j*) Obtains bearings, but not ranges, on other ships equipped with radar operating on the same frequency at distances in excess of the maximum from which echoes can be received.

(*k*) Ranges on land up to 50 miles.

4. Submarine Radar Equipment. Navy Types: SD, SJ, SS, ST, SV.

(*a*) Provides warning of presence of aircraft and surface vessels either while submarine is surfaced or submerged to periscope depth.

(*b*) Obtains accurate ranges, with optical bearings, on surface vessels while submarine is submerged to periscope depth, for use in torpedo control.

(*c*) Obtains accurate range and bearing data for torpedo control while submarine is surfaced, especially at night and in conditions of poor visibility.

(*d*) Obtains range and bearing on prominent landmarks and buoys as an aid to piloting.

(*e*) Permits very directional, secure communications between submarines within at least 30,000 yards.

5. Fire Control Radar Equipment. Navy types: Main battery—Mark 3, Mark 8, Mark 13. Secondary battery—Mark 4, Mark 12, Mark 22. Heavy machine guns—Mark 26, Mark 28, Mark 29, Mark 34.

(*a*) Supplies smooth, accurate ranges and fairly accurate bearings and position angles to the computer so that a solution to the fire control problem may be obtained more quickly than by optical means.

(*b*) Indicates spots in both range and deflection by ranging on shell splashes. At short ranges it is possible to follow the projectile on the radar throughout its entire flight.

(*c*) Can be used for calibrating anti-aircraft projectile fuses by comparing the range of the burst with the fuse setting.

(*d*) Supplies data for the direction of starshell or searchlight illumination.

(*e*) Obtains meteorological data by observing the movements of balloons equipped with radar reflectors.

(*f*) Detects low-flying aircraft.

(*g*) Supplies useful tactical data such as the position of other ships in own force, and greatly facilitates station keeping at night or in poor visibility.

(*h*) Detects surface craft in the event of failure of the surface search radar.

(*i*) Ranges on land up to 75 miles.

6. Repeater PPI Equipment.

(*a*) Standard Repeater PPI. Navy types: VC, VD, VE, VH, VJ, VK.

(1) Reproduces any desired PPI information at several selected locations remote from the radar room.

(2) Permits a given radar to be used in two or more applications simultaneously, such as station keeping and surface searching. This is especially true in the case of a system which is equipped with Sensitivity-Time Control (STC) and Instantaneous Automatic Volume Control (IAVC) because these features permit close-in echoes to be seen just as clearly as those at long range.

(3) In the presence of enemy jamming, the selector switch permits a rapid check of available radar frequencies to determine which is the least affected.

(4) Provides a means of revealing enemy deception by comparing the effect on several radars.

(5) Provides direct assistance in piloting and station keeping by showing the PPI indication of the surface search radar on the bridge.

(6) Provides, with the use of attachments that produce expanded sweeps, a more desirable presentation for use in controlling aircraft interceptions than is possible on many radar PPIs.

(*b*) Precision Repeater PPI Equipment. Navy type VF.

(1) Permits close observation of a small sector while the radar proper surveys the whole 360°.

(2) Obtains from surface search radar range data to an accuracy comparable to that from fire control radar, and bearing data that may be slightly more accurate than that obtained from the radar.

(3) Expands a small sector to cover a large area so that it is feasible to spot shell splashes in both range and deflection with reasonable accuracy.

(4) Enables a ship to keep on station within very small limits.

(5) Provides a means for transmitting range and bearing data for use in target indication.

(*c*) Projection Repeater PPI Equipment. Navy type VG.

(1) Eliminates time lag in plotting of radar data.

(2) Provides excellent surface on which to maintain a surface summary plot.

(3) Provides large surface which can be used as a plotting table for air plot or surface plot.

(4) Reduces plotting errors by simplifying plotting.

7. Recognition equipment for use with radar (IFF). Navy types: ABK, ABF, AN/APX-1, AN/APX-2, BK, BL, BM, BN, BO.

(*a*) Identifies on the radar screen the echoes from friendly aircraft and ships by returning a coded response during a 12-second period.

(*b*) Indicates the range and bearing of friendly aircraft at distances in excess of the maximum from which echoes can be obtained.

(*c*) Identifies to the Fighter Director Officer which echoes out of a group are the fighters over which he has control. This identification is made on the G band and is instantaneous and uncoded.

(*d*) Acts as a beacon, using a code selected for the purpose, to indicate contact with the enemy.

(*e*) Acts as a beacon on which aircraft can home.

(*f*) Indicates distress by producing on the radar screen an exceptionally wide signal. This signal should be used only by aircraft and ships that are in distress such that they are unlikely to be able to return to their base, or by vessels standing by another in distress.

(*g*) Indicates, by use of coded response, the role in which a particular craft is employed. For example: during an operation it might be desirable to allot different codes to high cover fighters, low cover fighters, bombers, reconnaissance aircraft, and ships.

(*h*) Provides navigational fix for a ship by a shore station observing range and bearing of IFF response.

(*i*) Allows radar to follow friendly planes through null areas in antenna pattern or through severe clutter like that produced by hilly terrain.

8. Radar Beacon Equipment — Racons. Navy types: YH, YJ, AN/CPN-3, AN/CPN-6, AN/CPN-8, Mk 1, Mk 2, Mk 4, Mk 5.

(*a*) Guides aircraft back to ship or shore base.

(*b*) Provides accurate navigational fixes.

(*c*) Provides point of aim for shore bombardment.

(*d*) Provides a small, isolated target for use in aligning radar antenna.

(*e*) Assists in a landing by helping to vector landing craft through restricted waters.

(*f*) May be useful in the presence of jamming since a powerful signal slightly off radar frequency is returned.

C. INTERPRETATION OF ECHOES

1. General.

The pips that appear on a radar indicator show only the presence of targets within the field of view of the radar. The position of the echo signals on the screen indicates range and bearing. Beyond this simple, measurable information the pips do not, of themselves, reveal any further data. However, there are small variations in the character of the echo signal that indicate, to some extent, the nature of the target. These variations are either imperceptible or meaningless to inexperienced observers.

After long experience in looking at a radar indicator, a good operator is able to interpret what he sees reliably, and often with a surprising degree of detail. To an untrained operator, the echo from one ship looks like the echo from any other ship. However, with proper training, the operator will often be able to estimate the type of ship detected. In fact, it has been reported that after the same group of ships had operated together for a long time, one radar operator could name several of the ships simply by observing the characteristics of their echoes.

2. Characteristics of Pips.

In general, there are four characteristics of pips that may give useful information:

(*a*) Size of pip.
(*b*) Shape of pip.
(*c*) Fading or fluctuation in height.
(*d*) Movement in range and bearing.

The operator will be able to distinguish between land, airplanes, and ships, and perhaps to estimate both the type and number of targets in a group by observing these characteristics of the echo signals.

The size of the pip depends on so many factors that reliance cannot be put in observation of this factor alone to estimate the type of target. However, since the size of the echo returned from a target at a given range depends on the magnitude of the target, the size of the echo may often be useful in indicating which targets of a group are large.

Because large targets can be detected at longer range than small ones, the range of first pick-up may be used as a basis for estimating the type of target detected. This estimate is complicated by the fact that several small targets in a group may be detected at a greater range than a single large target, and by the fact that target angle affects the size of the echo to some extent. However, at ranges greater than 15 to 20 miles, most ships are hull down so that the effect of target angle is negligible because the echo is returned from the mast and superstructure.

The shape of the echo is very useful as an indication of how many targets are in a group. In a formation of many planes, for example, the echo will spread over a long range, and on the A scope it will have many peaks. On a PPI scope, the shape and size of an echo may be such that the target could not be anything other than a cloud or a storm.

The amount and peculiarities of the fading of an echo pip often indicate the nature of the target. The echo returned from an airplane flutters rapidly and irregularly. This characteristic alone is often sufficient to enable the operator to select airplane echoes from others on his scope. A large ship generally produces a pip that bobs up and down slowly, while the echo from a small vessel flutters rapidly, especially in a rough sea. Land echoes are usually fairly steady, but when the sea is rough, some land echoes may flutter.

Plotting radar contacts over a period of time enables the course and speed of the target to be determined. If the speed is greater than 80 knots, the target must be an airplane, for even the relative speed of surface targets rarely exceeds 60 knots. Correlation of speed with the rate of flutter and the other characteristics of a pip frequently enables an estimate

to be made of the type of target. For example, a small echo that flutters violently and quickly, and which has a speed of 40 knots is probably a PT boat.

3. Type of Indicator.

Because the antenna must rotate continuously to produce a PPI presentation, the beam is never on a target long enough to allow the flutter of the echo to be apparent. The limiting of the echo signals that takes place before they are applied to the PPI tube removes most of the flutter that would tend to show. Consequently, practically no flutter shows on a PPI screen, so that this characteristic cannot be observed as an aid in interpreting the echo.

This disadvantage of the PPI scope is offset by the fact that it shows both range and bearing, enabling the disposition of a group of targets to be shown clearly on the screen. If the targets are separated sufficiently to allow the radar to resolve their echoes into separate pips, the number of targets is immediately apparent.

The targets, however, will often be so close together in range and bearing that they will show as a single bright spot on a PPI. In this case, the A scope permits a more reliable interpretation to be put on the pip because the number of peaks and the type of flutter can be observed. In order to observe these characteristics, the radar antenna must be stopped for thirty seconds or longer. This stoppage is very undesirable from the point of view of searching. If the antenna is frequently stopped for prolonged inspections of pips, serious damage may be inflicted by undetected enemy planes.

An expanded sweep spreads out the echoes, making it easier to interpret the pips accurately, since minor variations are easier to see. Thus an expanded sweep is advantageous not only because of the improved resolution possible, but also because of the more reliable interpretation that can be put on the echoes. This advantage applies equally to type A, type B and type PPI presentations.

D. CHARACTERISTICS OF SHIPBORNE RADARS

A knowledge of the operating characteristics of a particular radar equipment is necessary before either the capabilities or the limitations of the set can be appreciated. Therefore, some of the characteristics of radars that are in use and of radars soon to be available to the Fleet are presented in the following pages. Photographs of several types of naval vessels are included in order to indicate the locations of the antennas of as many of the current radars as possible. Not all types of ships are shown since those included illustrate both the typical placement of radar antennas and the complement of radars on the major classes of combatant vessels, but the photographs do not necessarily show the latest type allowances. The ships, and the radars normally installed on board them, are divided into three broad classes: large ships, small ships and auxiliaries, and submarines. A tabulation of the characteristics of the radars used in each of these classes is presented following the pictures of the ships. In the cases of duplication between two of these rather arbitrary classifications, as the SC-2, SG, and Mark 4 radars for example, the characteristics are included only once.

The characteristics of each radar are compiled on a single sheet. The data given for each set include: the model designation, the primary purpose, the frequency band, the antenna beam width, the types of indicator presentations used and the range scales provided, and the best available figures on the accuracy and resolution of the set. No data are given on the so-called maximum reliable range because of the rather great inconsistencies that appear in the reported figures. Until relatively recently, no absolute criterion has been available to the Fleet for judging the level of performance of a radar. Therefore, the reported maximum ranges have little meaning without their being qualified by this figure. However, with the wider use of echo boxes by the Fleet, it is expected that the radars will be more likely to be maintained at peak performance, so that this large variable will be nearly eliminated from reported ranges. It has been very convincingly demonstrated that the use of a "standard" target is by no means a reliable measure of performance (see Figure 100). In addition to the varying performance level, radar ranges are very greatly affected by conditions of propagation. In many cases atmospheric conditions exist which extend radar range far beyond the line of sight by trapping the radar pulses in a duct which guides them over the horizon and guides the echoes back to the antenna. In still other cases, the atmosphere can bend the path of the radar pulses upward so that surface coverage is markedly reduced. The weather conditions which cause these phenomena are detectable only by exhaustive meteorological soundings which are beyond the scope of the forces afloat. Since neither the true level of performance nor the existence of non-standard propagation is reported as such with the ranges obtained, the data available hardly form the basis for stating the reliable maximum ranges that can be expected with a given radar installation.

It will be noted that in many cases several models of radar are grouped together on one sheet, as the SC-2, SC-3, and SC-4. This grouping indicates that the operational characteristics of the sets in question are almost identical, although there may be some differences in the physical appearance of the sets or minor changes in the electrical circuits. The radio frequency

on which the set operates is stated as a letter because of security requirements.

An average figure is given for both the horizontal and vertical beam widths of the antenna. Not every SC-2 for example, has a horizontal beam width of exactly 20°, because it is impossible to build absolutely identical antennas and because the pattern is affected by the place in which the antenna is installed and by the frequency on which the set is operated. Thus the figures given indicate the approximate dimensions of the antenna beam of the type of radar in question, but not the precise shape of the beam of any particular set. Knowledge of the antenna pattern forms the basis for estimating the bearing resolution and it gives some indication of the possible bearing accuracy.

The types of indicator presentations are mentioned along with the range scales available on each type of indicator. These data should be helpful in appreciating both the range accuracy and the range resolution of which the set is capable. A photograph of the radar operating position is included as a means of promoting familiarization with the equipment.

Figures are presented to indicate the accuracy of the determination of range, bearing, and position angle or altitude for each set, even though it is well known that a single figure cannot truly state the accuracy of the set. There are properties inherent in a radar that limit the precision with which data can be measured. If only these factors are considered, a very optimistic picture of the accuracy of a radar will be obtained. Additional limitations imposed by operating conditions may reduce radar accuracy considerably. For example, if both the target and the radar are absolutely stationary at the manufacturing plant, it can be demonstrated that the bearing of the target can be determined repeatedly by relatively unskilled operators within a margin of error of perhaps 2 mils. The manufacturer might then conclude that the bearing accuracy of his equipment is ± 1 mil. However, when this radar is taken to sea, where the radar is far from absolutely stationary and the target may be an aircraft flying at 300 knots, even the most highly skilled operator cannot keep the radar beam on the target well enough to determine bearing closer than perhaps $1/2°$. Many other factors, of course, influence accuracy, so that stating single figures for accuracy may be very misleading. The figures given are intended to serve as guides, and in general they apply to the most expanded type of presentation available.

Resolution, like accuracy, depends on many factors, so that it cannot be stated exactly by a single figure. The figures shown on the illustrations are for the shortest range scale and for the type A scope in the case of search radars, unless otherwise indicated in the captions. The factors that affect resolution are discussed in Chapter V.

RADAR INSTALLATIONS ON LARGE SHIPS

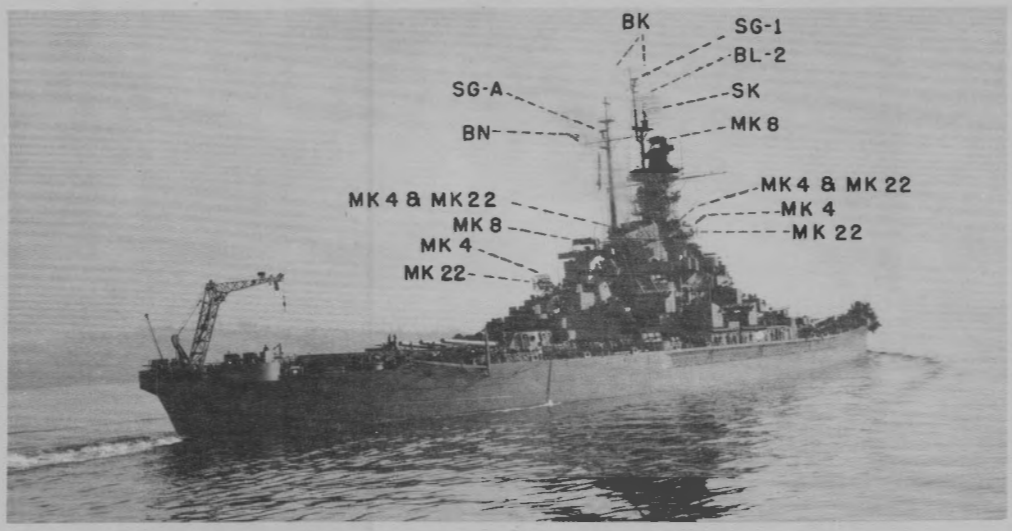


Figure 19—Battleship (BB).

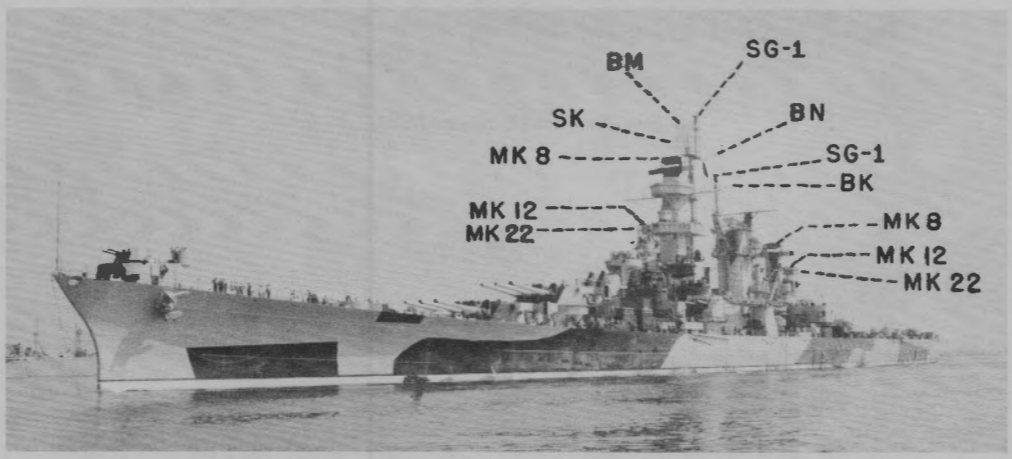


Figure 20—Large cruiser (CB).

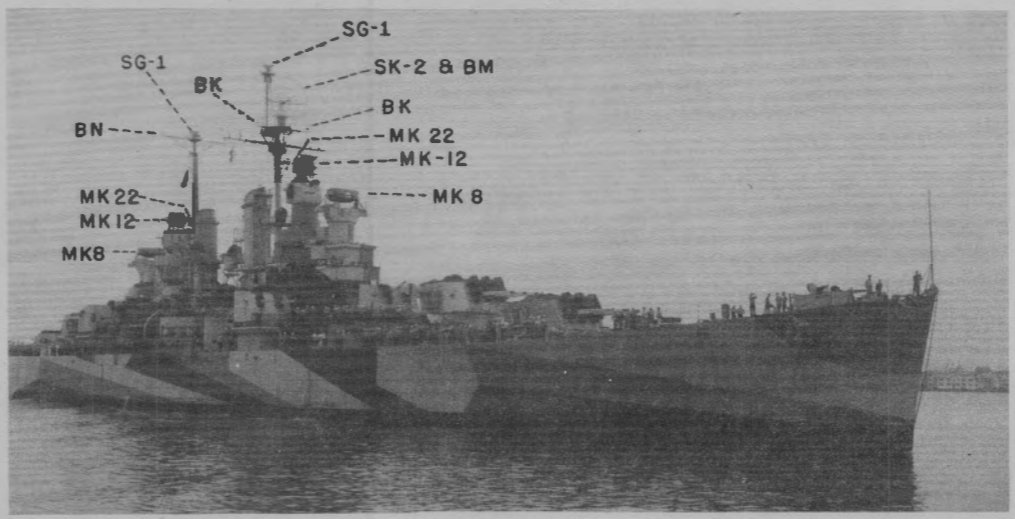


Figure 21—Light cruiser (CL).

RADAR INSTALLATIONS ON LARGE SHIPS

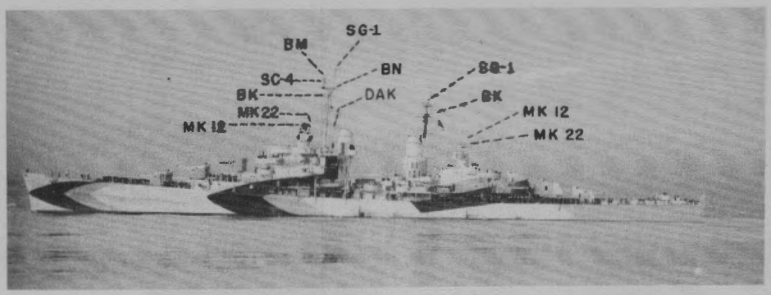


Figure 22—Antiaircraft cruiser (CL).

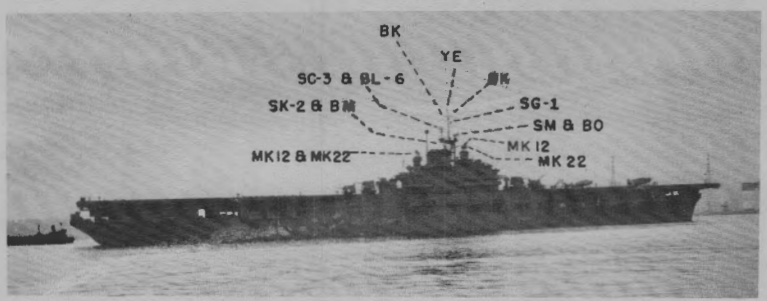


Figure 23—Aircraft carrier (CV).

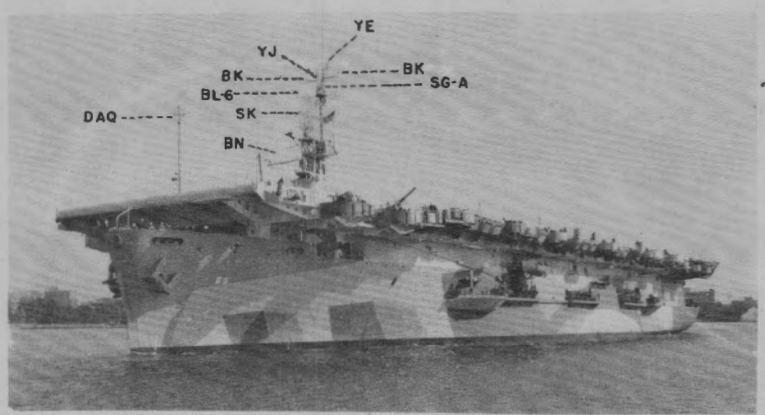


Figure 24—Auxiliary aircraft carrier (CVE).

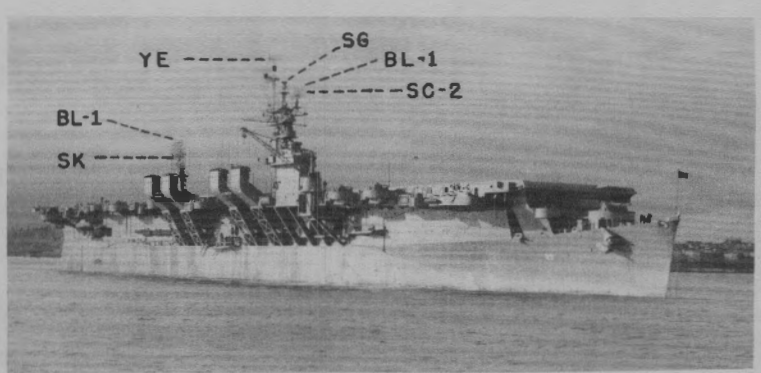


Figure 25—Aircraft carrier—small (CVL).

MODELS SC-2, SC-3, SC-4, SK, SK-2

PURPOSE—Air search

FREQUENCY BAND—P

ANTENNA BEAM WIDTH:

	SC	SK
Horizontal	20°	20°
Vertical	60°	20°

PULSE DURATION: 5 microseconds

ACCURACY:

Range, ±150 yards on short range scale

Bearing, ±3°

Altitude, ±2,000 feet with calibrated fade chart

INDICATOR:

Type scope		*Range scales*
SC-2, SK	A	15, 75, 375 mi.
SC-3, SC-4, SK-2	A	20, 80, 400 mi.
12″ PPI		20, 75, 200 mi.

MINIMUM RANGE: 1,200 yards

Figure 26—SK operating position.

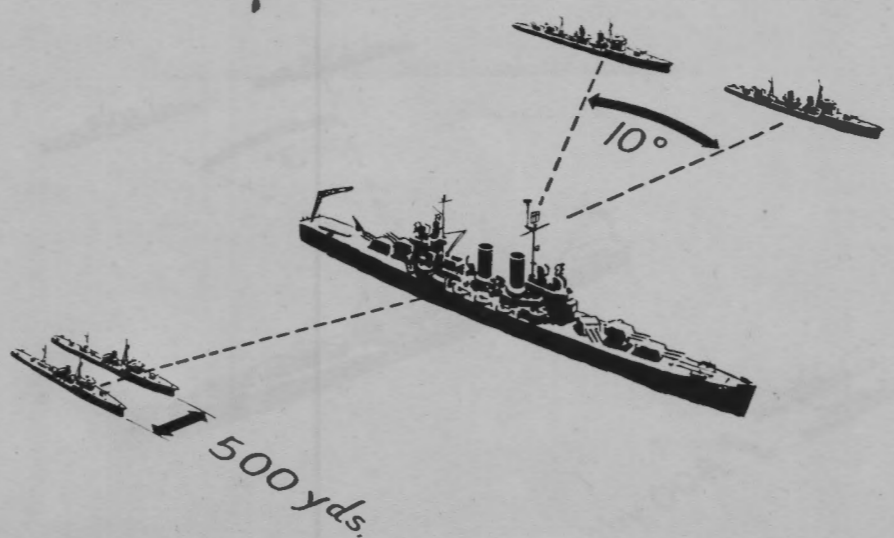


Figure 27—Approximate resolution on short range scale.

MODELS SG-a, SG-1

PURPOSE—Surface search

FREQUENCY BAND—S

ANTENNA BEAM WIDTH:

Horizontal 5.6°
Vertical, 15°

MINIMUM RANGE: 600 yards

ACCURACY:

Range, ±200 yards on 15,000-yard range scale
Bearing, ±2°
Altitude, not indicated

PULSE DURATION: 2 microseconds

INDICATOR:

Type scope	*Range scales*
A	15,000; 75,000 yards
9″ PPI	15,000; 75,000 yards

NOTE: Modernization (Change No. 50) provides 7″ PPI instead of 9″ and expansion of the A scope from step.

Figure 28—SG operating position.

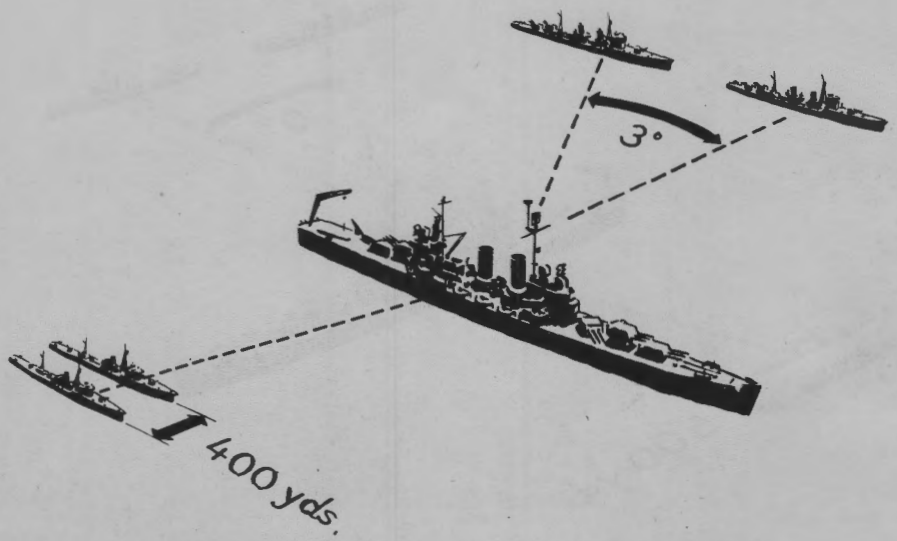


Figure 29—Approximate resolution on short range scale.

MODELS SG-3, SG-4

PURPOSE—Surface search

FREQUENCY BAND—S

ANTENNA BEAM WIDTH:

	SG-3	SG-4
Horizontal,	3°	3°
Vertical	13°	6.5°

PULSE DURATION: 0.3 or 1¼ microseconds

INDICATOR:

Type scope	*Range scales*
A	4, 10, 20, 80, 400 mi.
5" PPI	4, 10, 20, 80, 200 mi.
R	5,000 yards

MINIMUM RANGE: 200 yards

NOTE: SG-4 antenna is stabilized; SG-3 antenna is not.

ACCURACY:

Range, ±100 yards on 20-mile range scale
Bearing, ±¾°
Altitude, no indication

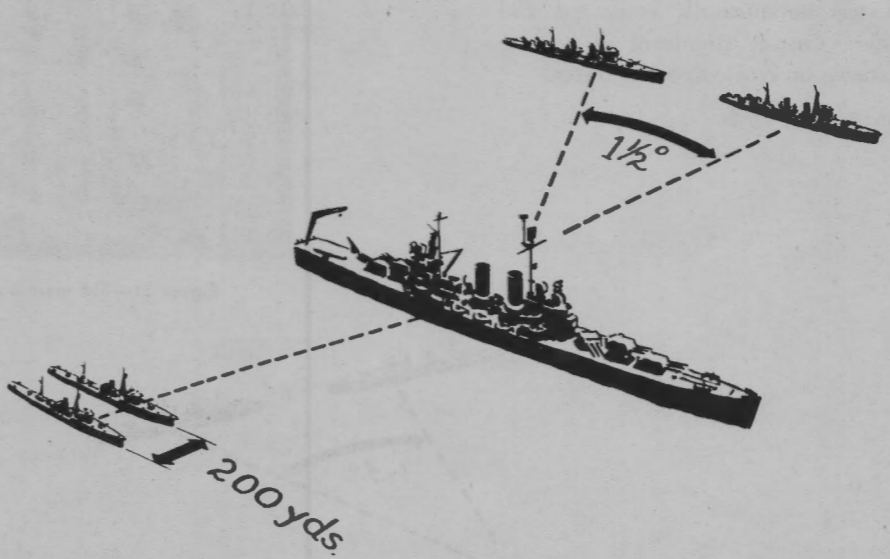


Figure 30—Approximate resolution on 20-mile scale.

MODEL SM

PURPOSE—Low-angle search and height finding

FREQUENCY BAND—S

ANTENNA BEAM WIDTH:

	Wobbler Off	Wobbler On
Horizontal	2.5°	4°
Vertical	3°	4.5°

NOTE: Antenna may be elevated over a range of —3° to +75°; antenna is stabilized.

PULSE DURATION: 1 microsecond

ACCURACY:

Range, ± 200 yards or ±¼% of range scale, whichever is larger.
Bearing, ±½° with wobbler (conical scanning) on.
Altitude, ±½° above 3.5° position angle, with wobbler on.

INDICATOR:

Type scope	*Range scales*
A	80 miles
7″ PPI	10, 50, 80 miles
R	4,000 yards

Position angle indicated on dial.

Altitude in feet automatically computed and shown on meter. Correct alignment in bearing and elevation shown on crossed-pointer meter.

MINIMUM RANGE: 600 yards

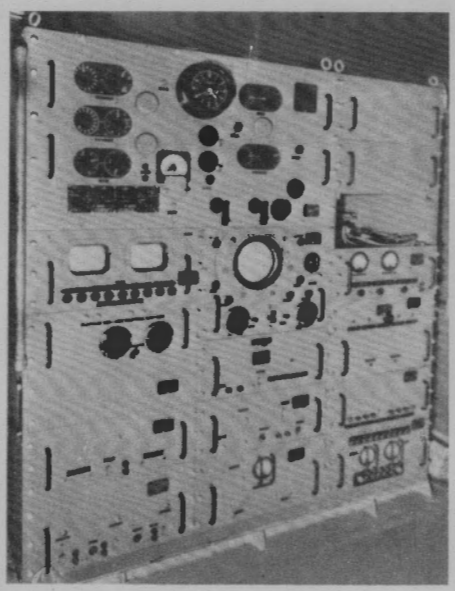


Figure 31—SM main console.

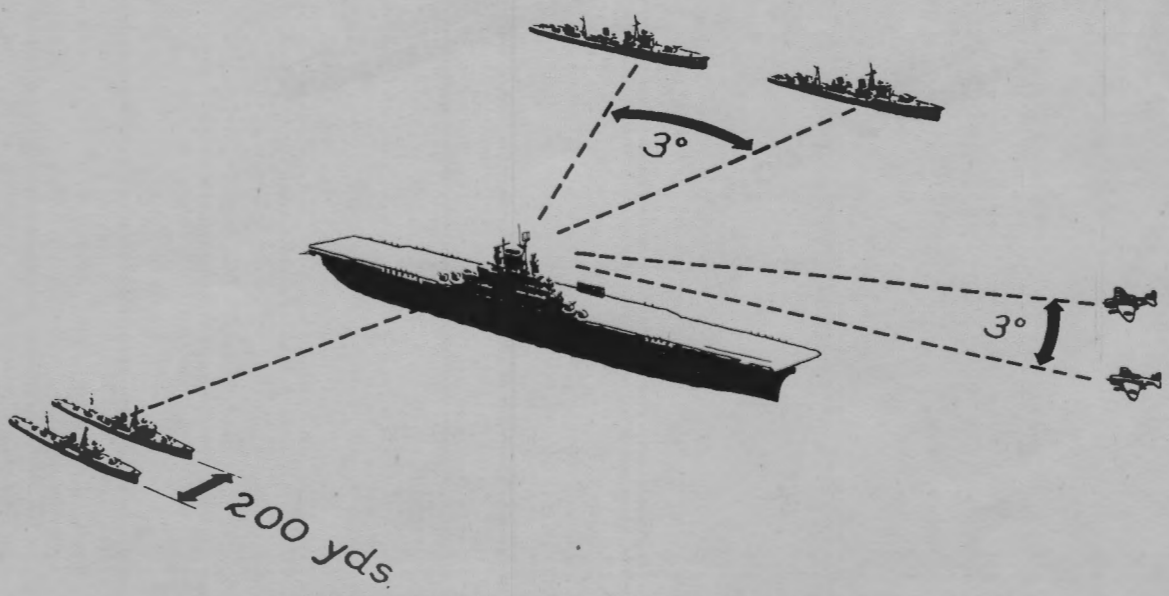


Figure 32—Approximate resolution at medium range.

MODEL SP

PURPOSE—Low-angle search and height finding

FREQUENCY BAND—S

ANTENNA BEAM WIDTH:

	Wobbler Off	Wobbler On
Horizontal	3°	4°
Vertical	3°	4°

NOTE: Antenna may be elevated between 0 and +30°; antenna is stabilized.

MINIMUM RANGE: 600 yards

ACCURACY:

Range, ±200 yards or ±¼% of range scale, whichever is larger.
Bearing, ±½° with wobbler (conical scanning) on.
Altitude, ±½° above 3° position angle, with wobbler on.

PULSE DURATION: 1 or 5 microseconds

INDICATOR:

Type scope	*Range scales*
A	100 miles
7″ PPI	4, 20, 50, 100, 200 miles
R	5 miles

Position angle indicated on dial. Altitude in feet automatically computed, with correction for earth curvature included, and shown on meter. Correct alignment in bearing and elevation shown on moving spot scope.

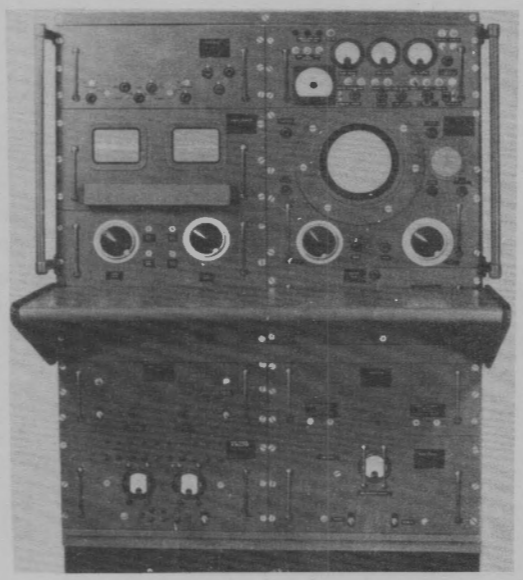


Figure 33—SP operating position.

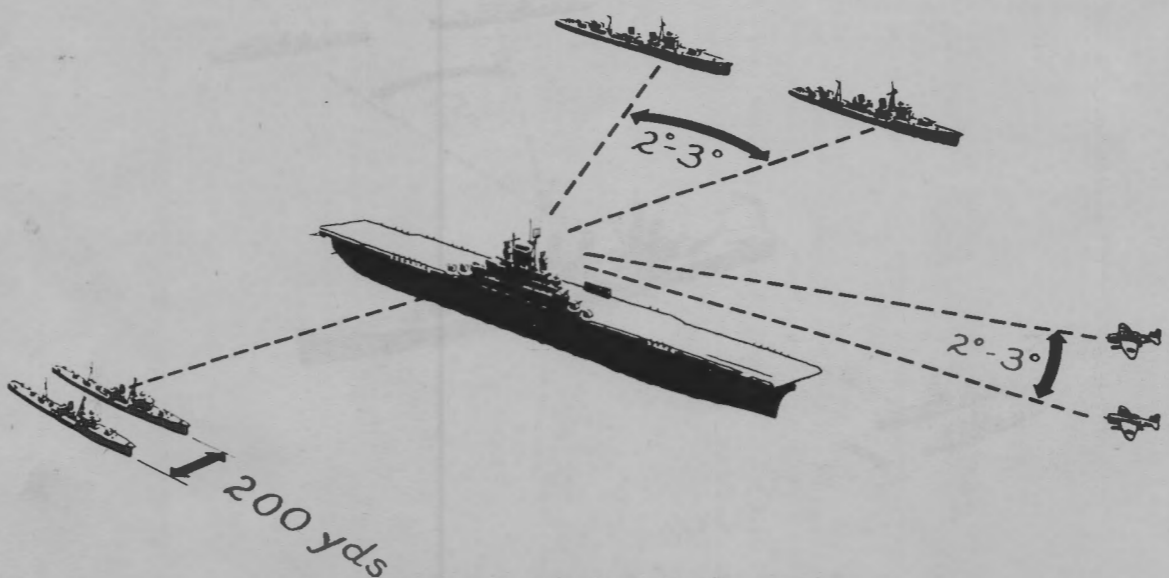


Figure 34—Approximate resolution at medium range.

MODEL SQ

PURPOSE—Standby surface search

FREQUENCY BAND—S

ANTENNA BEAM WIDTH:

Horizontal	8°
Vertical	15°

PULSE DURATION: 1 microsecond

ACCURACY:

Range, ±200 yards on 15-mile scale; ±1500 yards on 45-mile scale
Bearing, ±2°
Altitude, no indication

INDICATOR:

Type scope	*Range scales*
A	3, 15, 45 miles
B	3, 15, 45 miles
3″ PPI	3, 15, 45 miles

NOTE: Choice of type A, B, or PPI presentation on single scope by means of switch.

MINIMUM RANGE: 300 yards

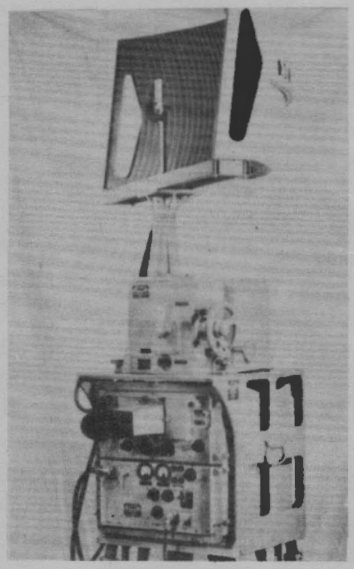


Figure 35—SQ operating position.

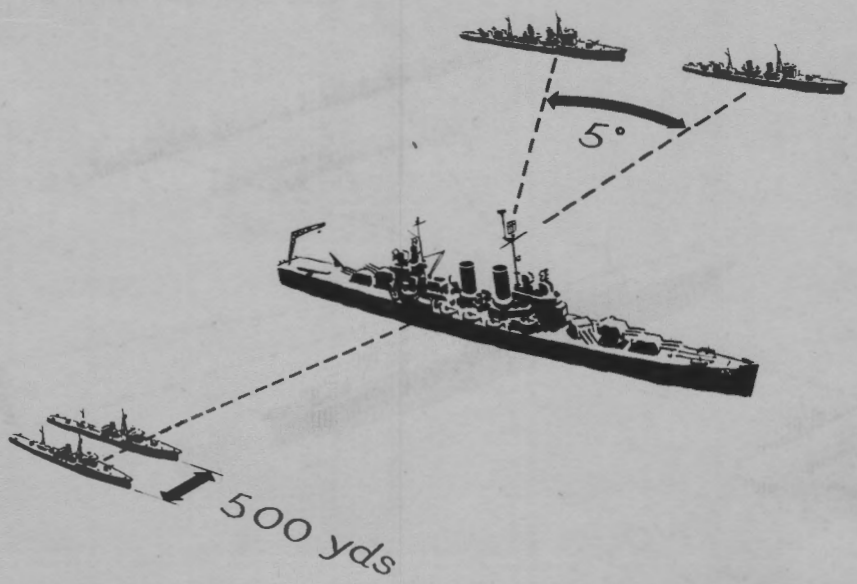


Figure 36—Approximate resolution on 45-mile scale.

MODEL SR

PURPOSE—Air search

FREQUENCY BAND—P

ANTENNA BEAM WIDTH:

Horizontal	20°
Vertical	55°

PULSE DURATION: 1, 4, or 20 microseconds

ACCURACY:

Range, ±30 yds. on 4-mi. scale; ±100 yds. on 20 mi.; ±2000 yds. on 80 mi.; ±10 mi. on 400-mi. scale

Bearing, ±2°

Altitude, ±2000 feet with calibrated fade chart

INDICATOR:

Type scope	*Range scales*
A	4, 20, 80, 400 miles
7″ PPI	4, 20, 80, 200 miles

MINIMUM RANGE: 750 yards

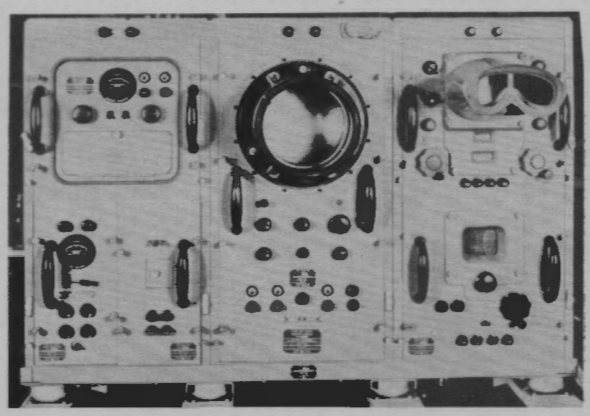


Figure 37—SR operating position.

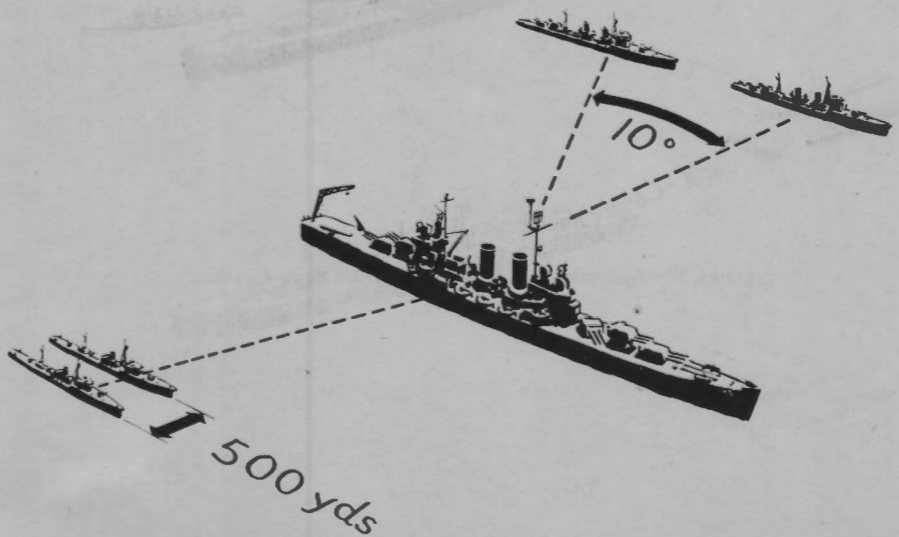


Figure 38—Approximate resolution at medium range.

MODEL SR-2

PURPOSE—Air search

FREQUENCY BAND—L

ANTENNA BEAM WIDTH:

Horizontal	8°
Vertical	25°

PULSE DURATION: 1 or 4 microseconds

INDICATOR:

Type scope	*Range scales*
A	4, 20, 80, 400 miles
7″ PPI	4, 10, 20, 80, 200 miles
R	2000 yards from step

MINIMUM RANGE: 600 yards

ACCURACY:

Range, ±30 yds. on 4-mi. scale; ±100 yds. on 20 mi.; ±2000 yds. on 80 mi.; ±10 mi. on 400-mi. scale
Bearing, ±2°
Altitude, not indicated

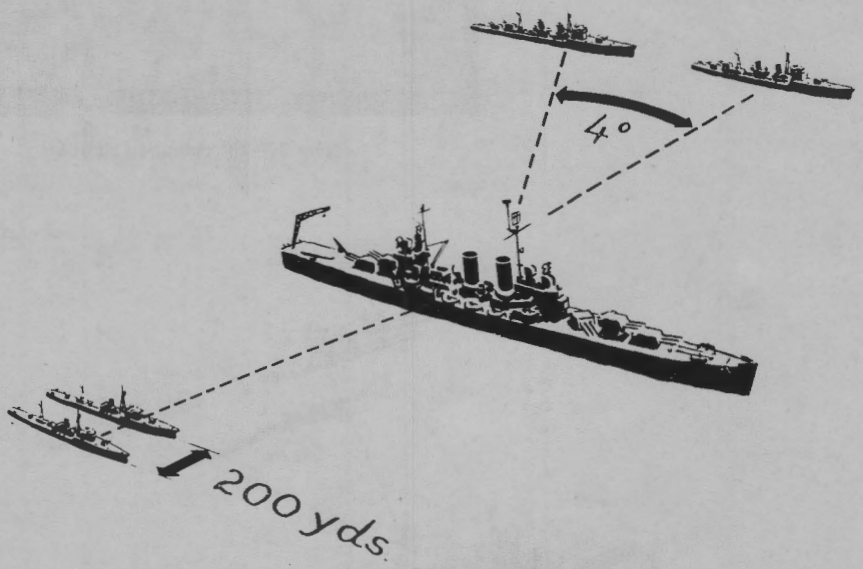


Figure 39—Approximate resolution with short pulse duration.

MODEL SX

PURPOSE—General purpose search

FREQUENCY BAND—S

ANTENNA BEAM WIDTH:

	Search	Height finding
Horizontal	1.6°	4°
Vertical	18°	1.2°

NOTE: Antenna stabilized; height-finding beam scans 12° arc vertically.
Two separate radar systems used—one for long-range search, the other for height finding.

PULSE DURATION: 1 microsecond for both systems

ACCURACY:

Range, ±200 yards on expanded presentations

Bearing, ±½°

Altitude, ±½° absolute; relative altitude may be determined more accurately

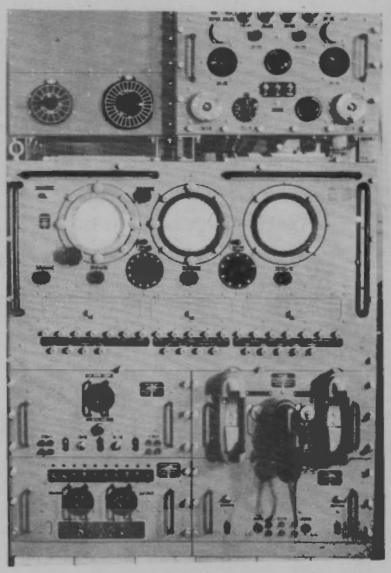


Figure 40A—SX operating console.

INDICATOR:

Type scope	*Range scales*
7″ PPI	0-50; 0-100; 70-90 mi.
Off-center PPI	10 miles
RHI	0-55; 10 mi. expanded sweep

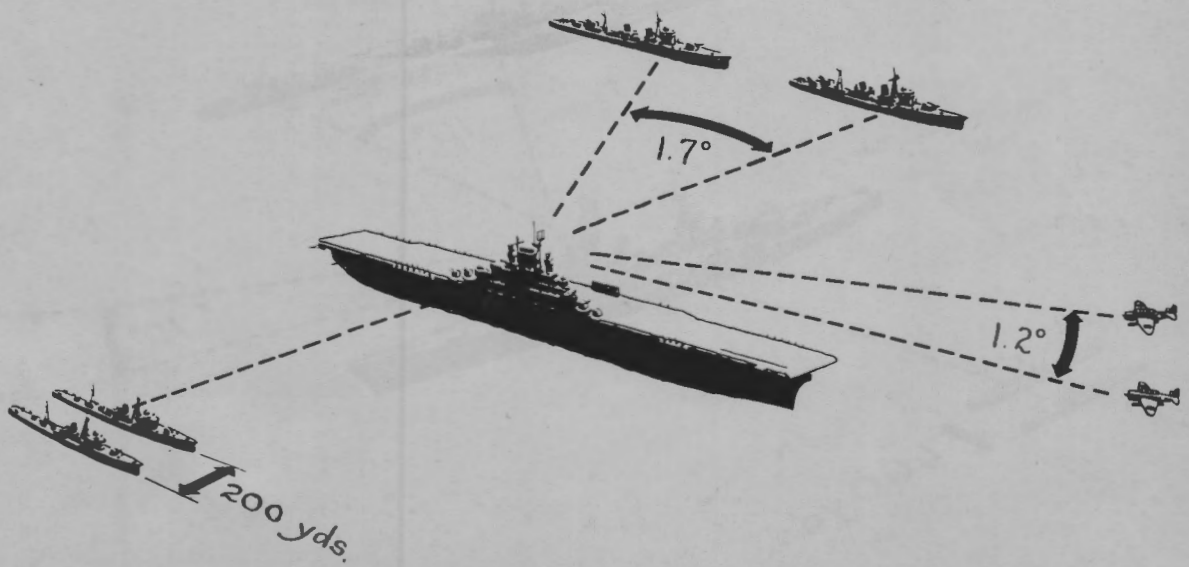


Figure 40—Approximate resolution at medium range.

MODEL MK 4

PURPOSE—AA fire control for Mk 37 director

FREQUENCY BAND—L

ANTENNA BEAM WIDTH:

	Lobing off	Lobing on
Horizontal	9°	15°
Vertical	9°	15°

NOTE: Antenna stabilized in level and cross level.

PULSE DURATION: 1.5 microseconds

ACCURACY:

Range, ±50 yards
Bearing, ±4 mils
Altitude, ±5 mils above 10° position angle

INDICATOR:

Type scope	*Range scale*
A with notch	100,000 yards

Sweep is expanded at notch.

Trainer and pointer scopes provided on which pips can be matched.

MINIMUM RANGE: 1000 yards

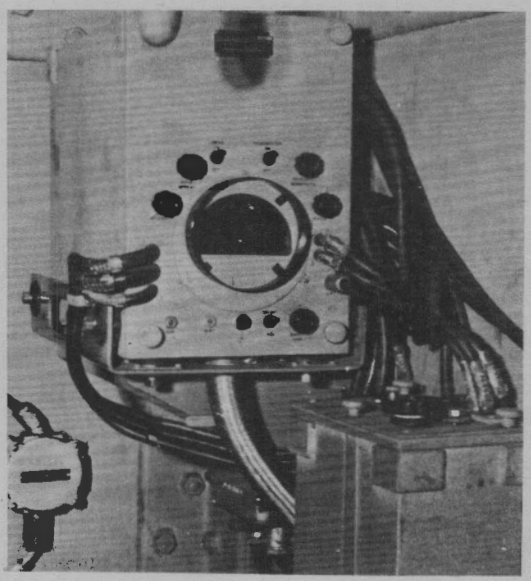


Figure 41—MK 4 range operator's position.

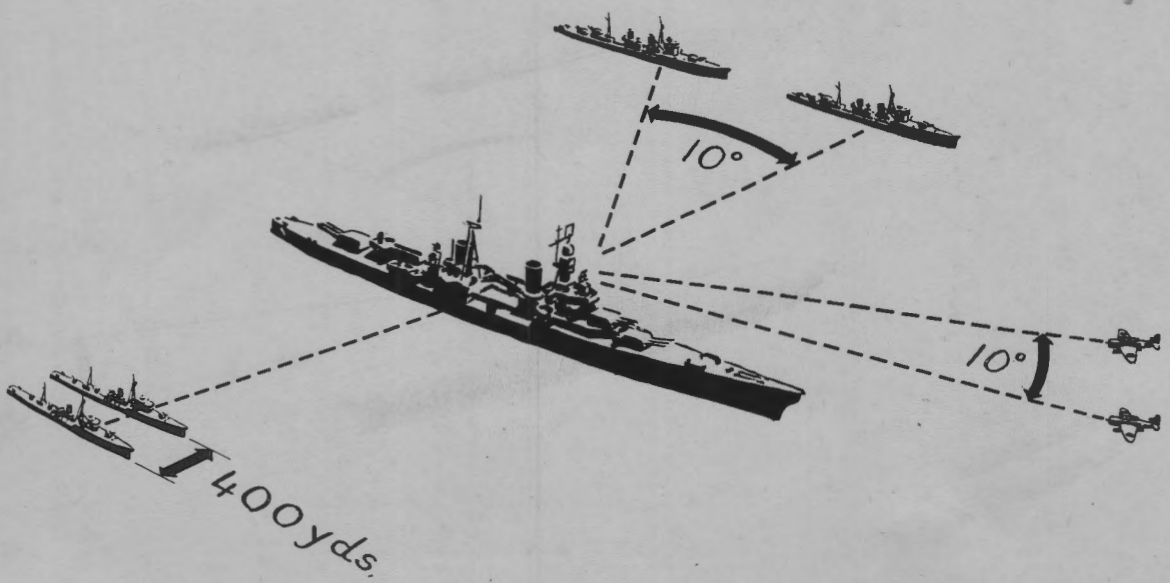


Figure 42—Approximate resolution.

MODEL MK 8, MODS 0, 1, 2

PURPOSE—Main battery fire control for Mk 34 and Mk 38 directors

FREQUENCY BAND—S

ANTENNA BEAM WIDTH:

Horizontal	2°
Vertical	3°

NOTE: Stabilized in level only.

PULSE DURATION: 0.4 microsecond

ACCURACY:

Range, ±15 yards ±0.1% of actual range
Bearing, ±2 mils
Altitude, not indicated

INDICATOR:

Type scope	*Range scales*
A	20,000; 60,000 yards
B	20,000; 60,000 yards
Precision A or B	2500 yards

Type of display selected by switch—only one type available at one time.

B scope shows area 29° wide.

MINIMUM RANGE: 250 yards

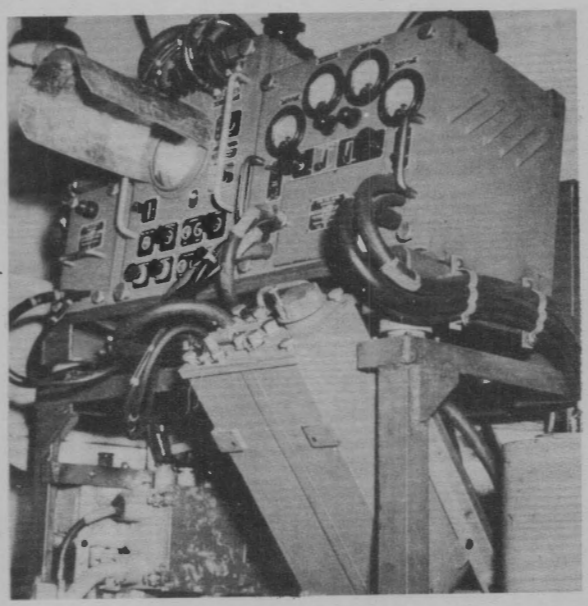


Figure 43—MK 8 mod 2 operating position.

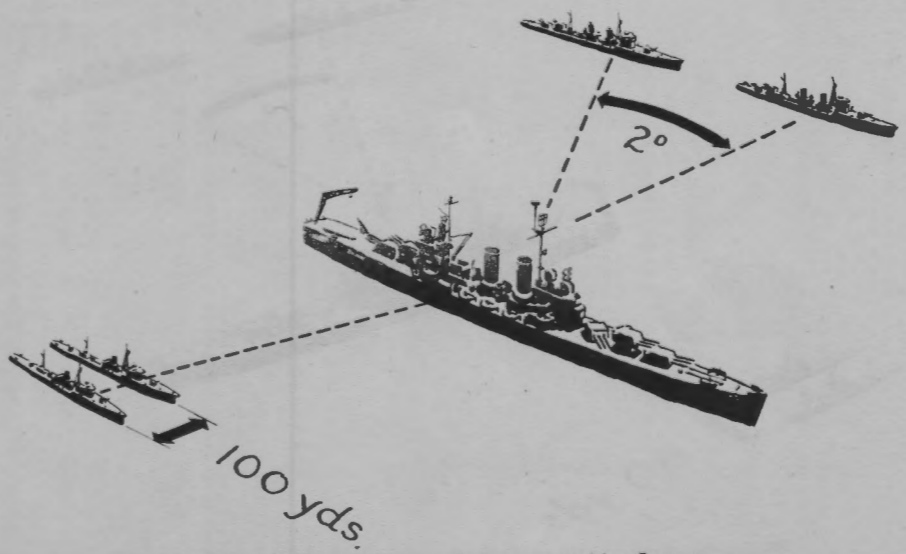


Figure 44—Approximate resolution on precision B scope.

MODEL MK 8, MODS 3, 4; MK 13, MODS 0, 2

PURPOSE—Main battery fire control for Mk 34 or Mk 38 directors

FREQUENCY BAND—X

ANTENNA BEAM WIDTH:

	Mk 8 mod 3, Mk 13 mod 0	Mk 8 mod 4, Mk 13 mod 2
Horizontal	0.9°	0.75°
Vertical	3.5°	4°

NOTE: Stabilized in level.

PULSE DURATION: 0.4 microseconds

ACCURACY:

Range, ± 15 yards ±0.1% of actual range
Bearing, ±2 mils
Altitude, not indicated

INDICATOR:

Type scope	*Range scales*
A	40,000; 80,000 yards
B	40,000; 80,000 yards
Precision A or B	2000-5000 yards

Type of display selected by switch.
Mk 8 mod 3 and Mk 13 mod 0
B scopes show area 11° wide
Mk 8 mod 4 and Mk 13 mod 2
B scopes show area 14° wide

MINIMUM RANGE: 250 yards

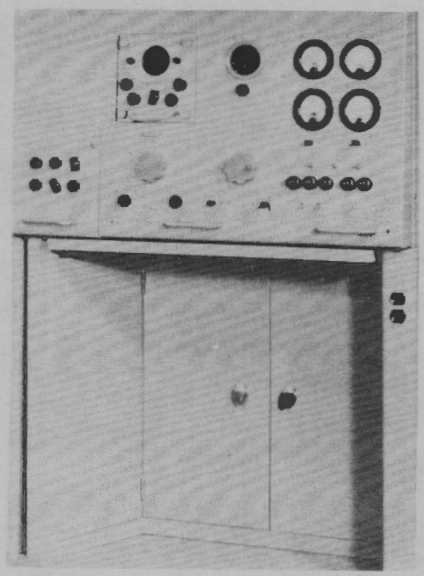


Figure 45—MK 13 operating position.

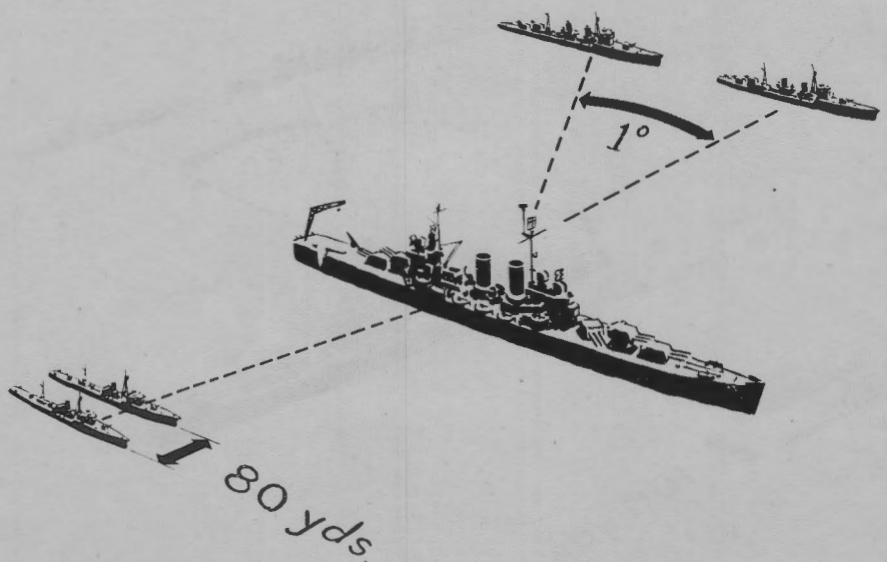


Figure 46—Approximate resolution on precision B scope for MK 13 mod 0.

MODEL MK 12

PURPOSE—AA fire control for Mk 37 director

FREQUENCY BAND—L

ANTENNA BEAM WIDTH:

	Lobing Off	Lobing On
Horizontal	7°-10°	12°-15°
Vertical	8°-11°	13°-16°

NOTE: Stabilized in level and cross level.

PULSE DURATION: 1.2 microseconds

ACCURACY:

Range, ±15 yards ±0.1% of actual range
Bearing, ±3 mils on slow moving targets
Altitude, ±3 mils on slow moving targets above 7° position angle

INDICATOR:

Type scope	*Range scale*
A with notch	50,000 yards

A with pip matching for bearing or elevation.
Moving spot for bearing or elevation.
Sweep may be expanded 400 yards each side of notch.

MINIMUM RANGE: 400 yards

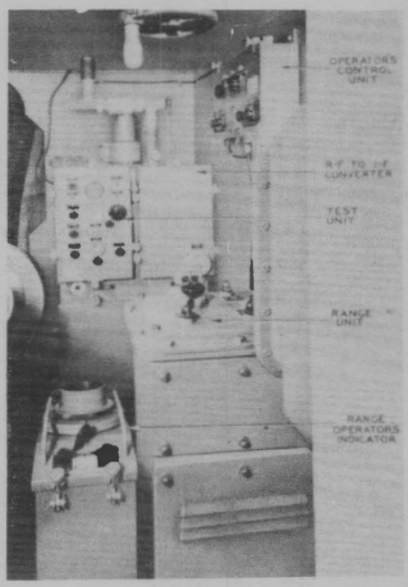


Figure 47—MK 12 range operator's position.

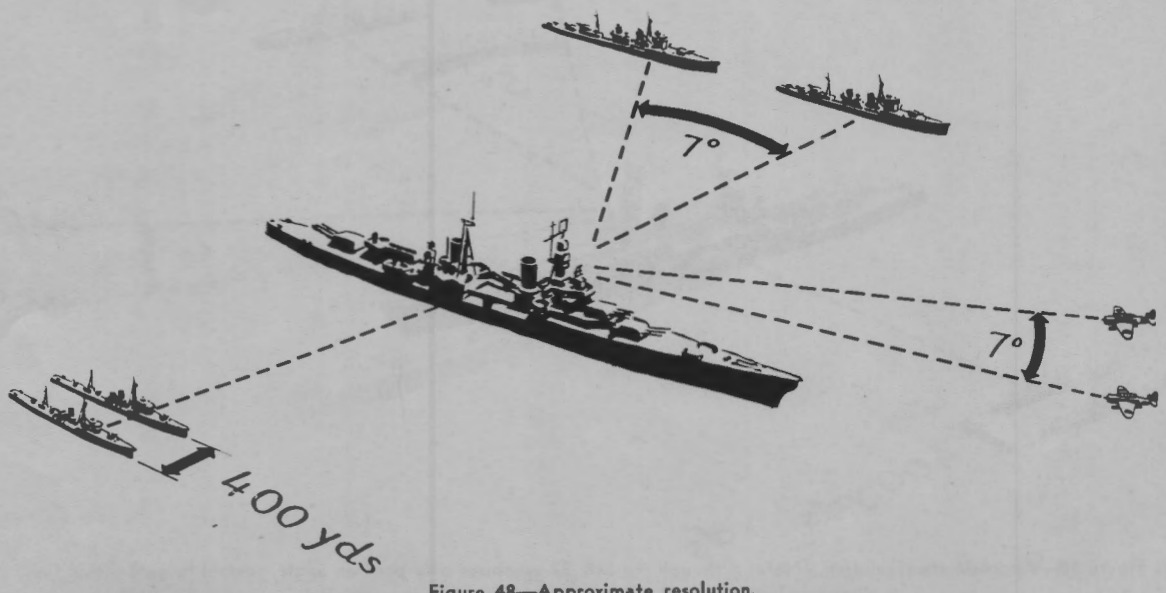


Figure 48—Approximate resolution.

MODEL MK 22

PURPOSE—Low-angle height finding for use with Mk 4 or Mk 12 radars

FREQUENCY BAND—X

ANTENNA BEAM WIDTH:

Horizontal	4.5°
Vertical	1.2°

NOTE: Beam is scanned vertically between —7° and +6° relative to optical axis at 1 cycle per second.

ACCURACY:

Range, none.
Bearing, none
Altitude, ±3 mils above 1° position angle

PULSE DURATION: 0.5 microsecond

INDICATOR:

Special indicator used. Shows only echo in notch of radar with which Mk 22 is used. Does not show range or bearing, but does indicate when Mk 22 beam is on in position angle.

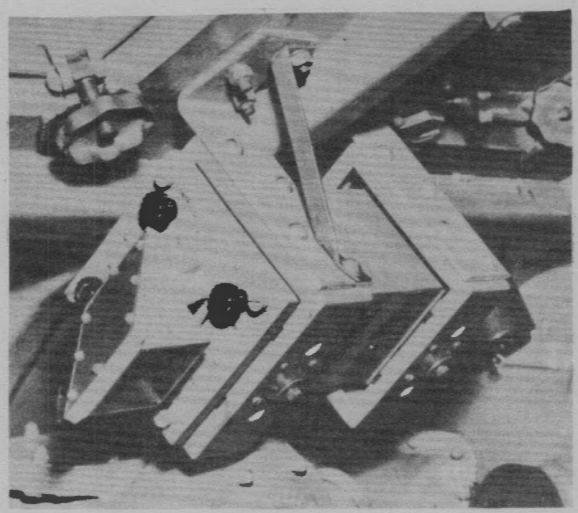


Figure 49—MK 22 indicator.

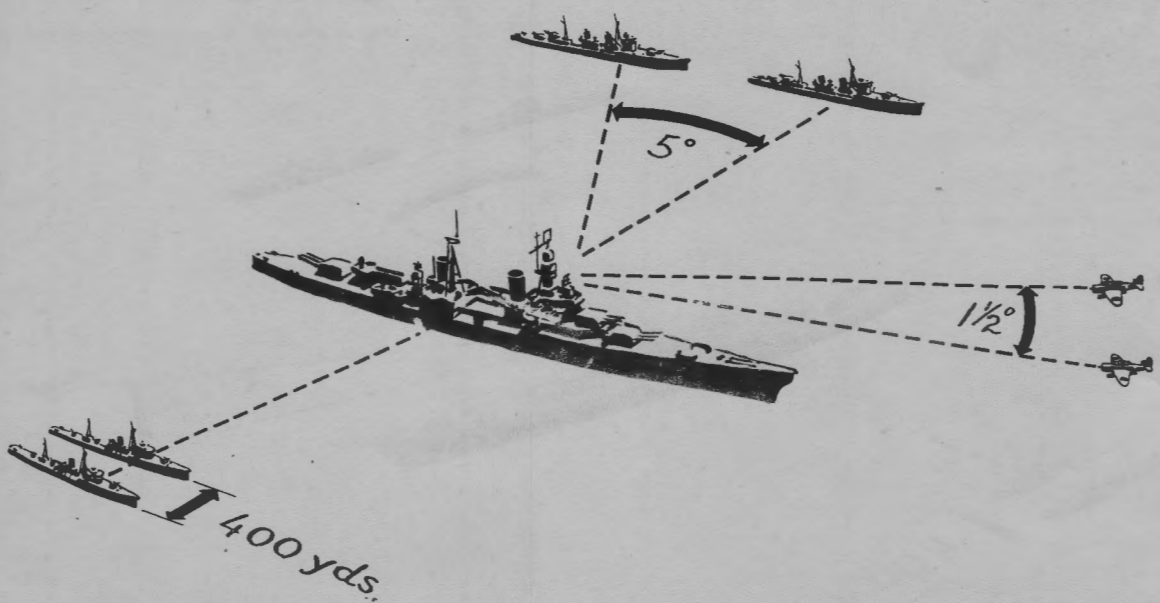


Figure 50—Approximate resolution. (Note: Although the MK 22 measures only position angle, several targets within the distances indicated will confuse position angle measurement.)

MODEL MK 28, MODS 0, 2, 3

PURPOSE—AA fire control
Mods 0, 3 for Mk 33 or Mk 37 director
Mod 2 for Mk 63 fire control system

FREQUENCY BAND—S

ANTENNA BEAM WIDTH:

	Conical Scanning Off	Conical Scanning On
Horizontal	6.8°	11.5°
Vertical	6.8°	11.5°

PULSE DURATION: 0.5 microsecond

NOTE: Antenna elevates from —25° to +110° on mods 0 and 3, and from —15° to +85° on mod 2.

ACCURACY:

Range, ±15 yards ±0.1% of actual range
Bearing, ±4 mils with conical scanning on.
Altitude, ±4 mils above 7° position angle, with conical scanning on

INDICATOR:

Type scope	*Range scales*
A	10,000; 60,000 yards
R	2500 yards

Moving spot for bearing and elevation.

MINIMUM RANGE: 400 yards

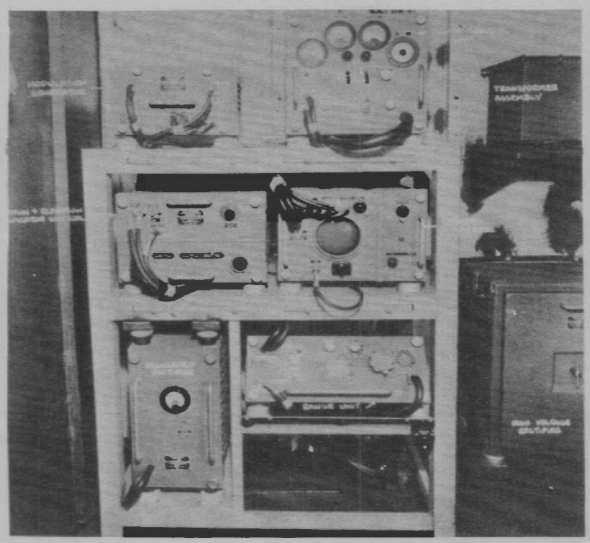


Figure 51—MK 28 operation position.

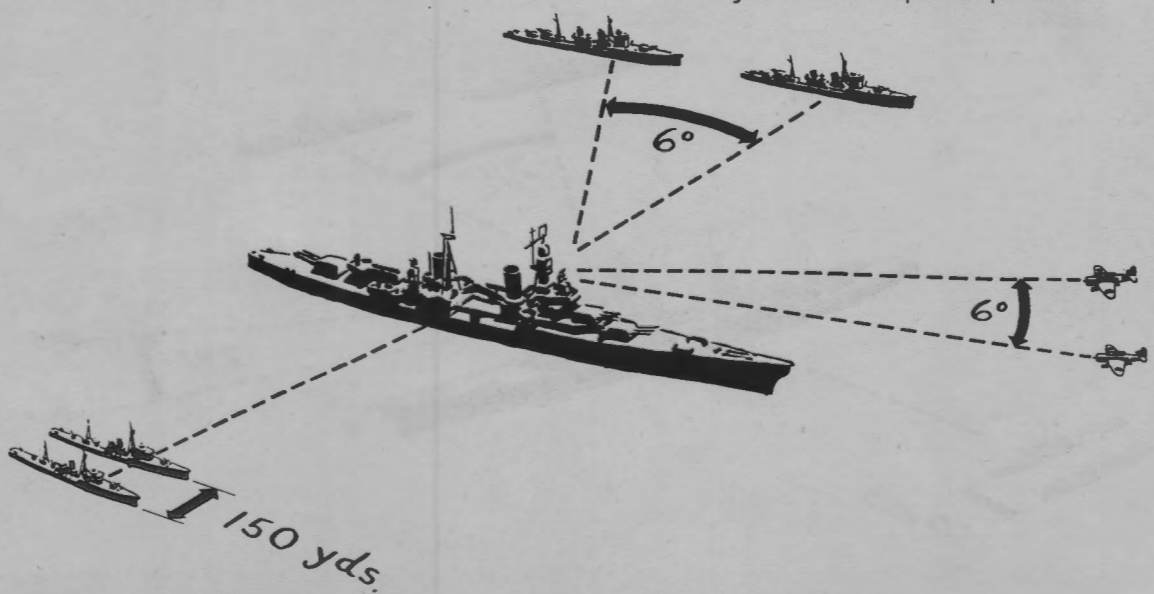


Figure 52—Approximate resolution on expanded scope with conical scanning on.

MODEL MK 29

PURPOSE—AA fire control for Mk 57 director

FREQUENCY BAND—X

ANTENNA BEAM WIDTH:

	Conical Scanning Off	Conical Scanning On
Horizontal	2.5°	5°
Vertical	2.5°	5°

NOTE: Antenna elevates from —15° to +85°.

PULSE DURATION: 0.5 microsecond

ACCURACY:

Range, ±15 yards ±0.1% of actual range
Bearing, ±2 mils with conical scanning on
Altitude, ±2 mils above 3° position angle, with conical scanning on

INDICATOR:

Type scope	*Range scales*
A	10,000; 40,000 yards
R	2500 yards

Moving spot for bearing and elevation.

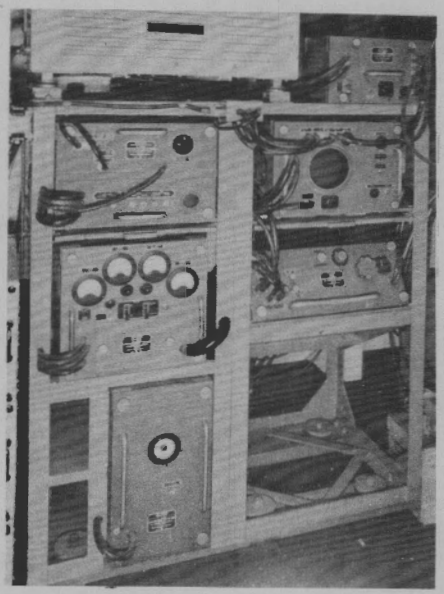


Figure 53—MK 29 operation position.

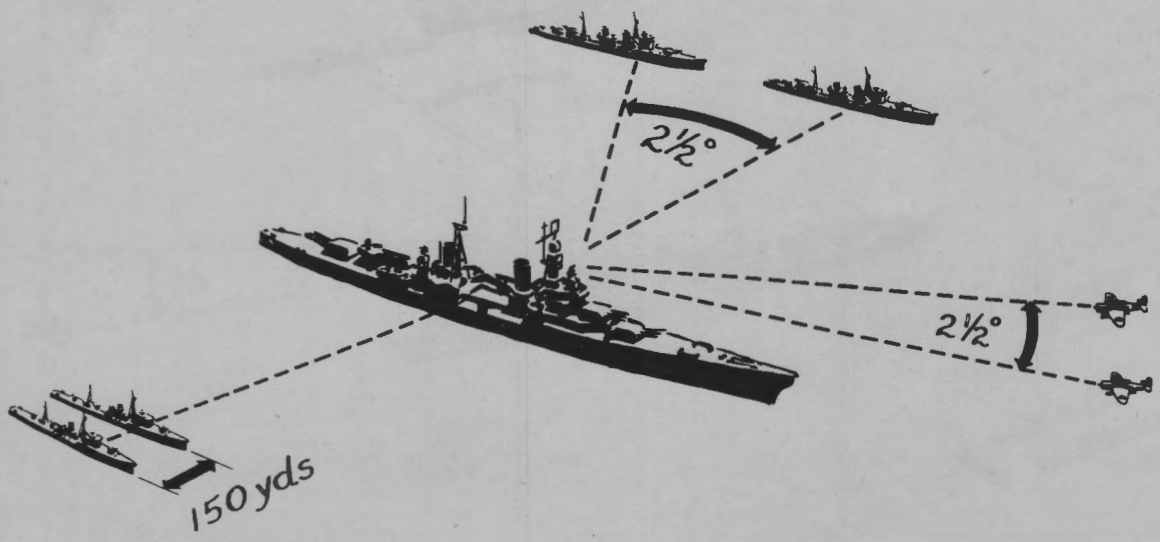


Figure 54—Approximate resolution on precision scope.

MODEL MK 34, MODS 0, 1, 2, 3, 4

PURPOSE—AA fire control
Mods 1, 2 for Mk 63 fire control system
Mods 3, 4 for Mk 57 director

FREQUENCY BAND—X

ANTENNA BEAM WIDTH:

	Conical Scanning Off	Conical Scanning On
Horizontal	3°	4.5°
Vertical	3°	4.5°

PULSE DURATION: 0.3 microsecond

INDICATOR:

Type scope	*Range scales*
A	10,000; 40,000 yards
R	2500 yards

Moving spot for bearing and elevation.

MINIMUM RANGE: 300 yards

NOTE: Antenna can be elevated between —15° and +85°. Stabilized in both level and cross level.

ACCURACY:

Range, ±15 yards ±0.1% of actual range
Bearing, ±2 mils with conical scanning on.
Altitude, ±2 mils above 4°, with conical scanning on

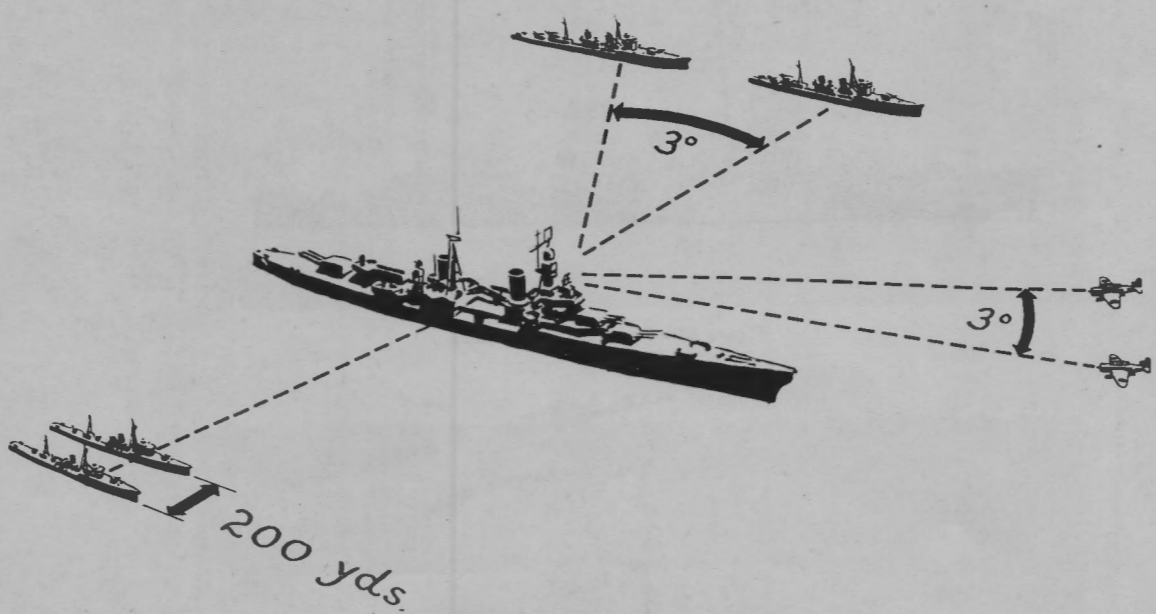


Figure 55—Approximate resolution on precision scope.

RADAR INSTALLATIONS IN SMALL SHIPS AND AUXILIARIES

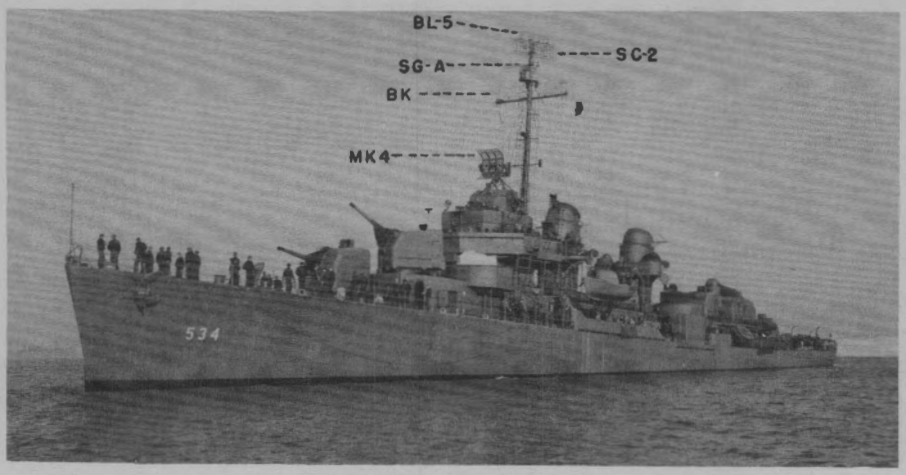


Figure 56—Destroyer (DD).

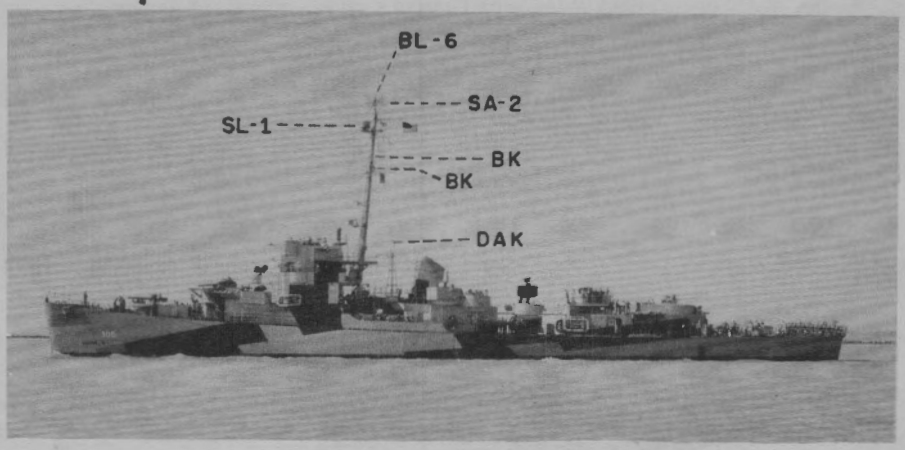


Figure 57—Destroyer escort (DE).

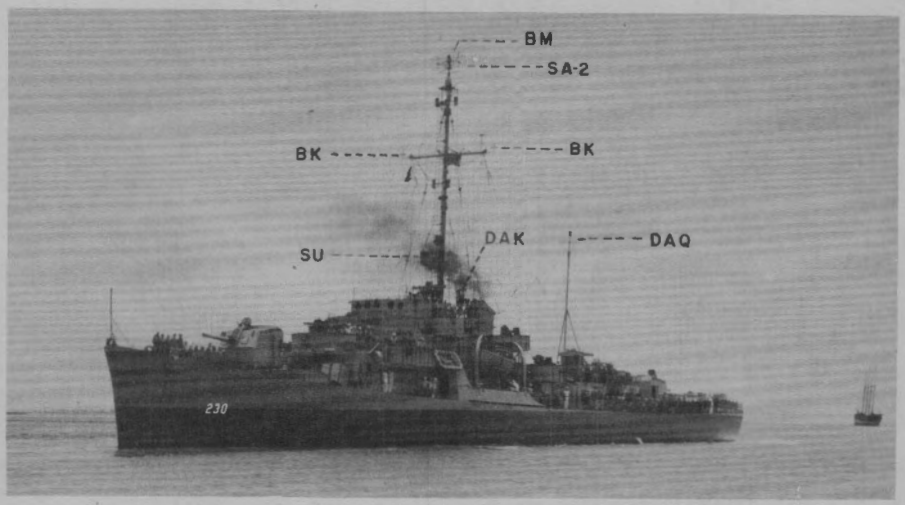


Figure 58—Destroyer escort (DE).

RADAR INSTALLATIONS IN SMALL SHIPS AND AUXILIARIES

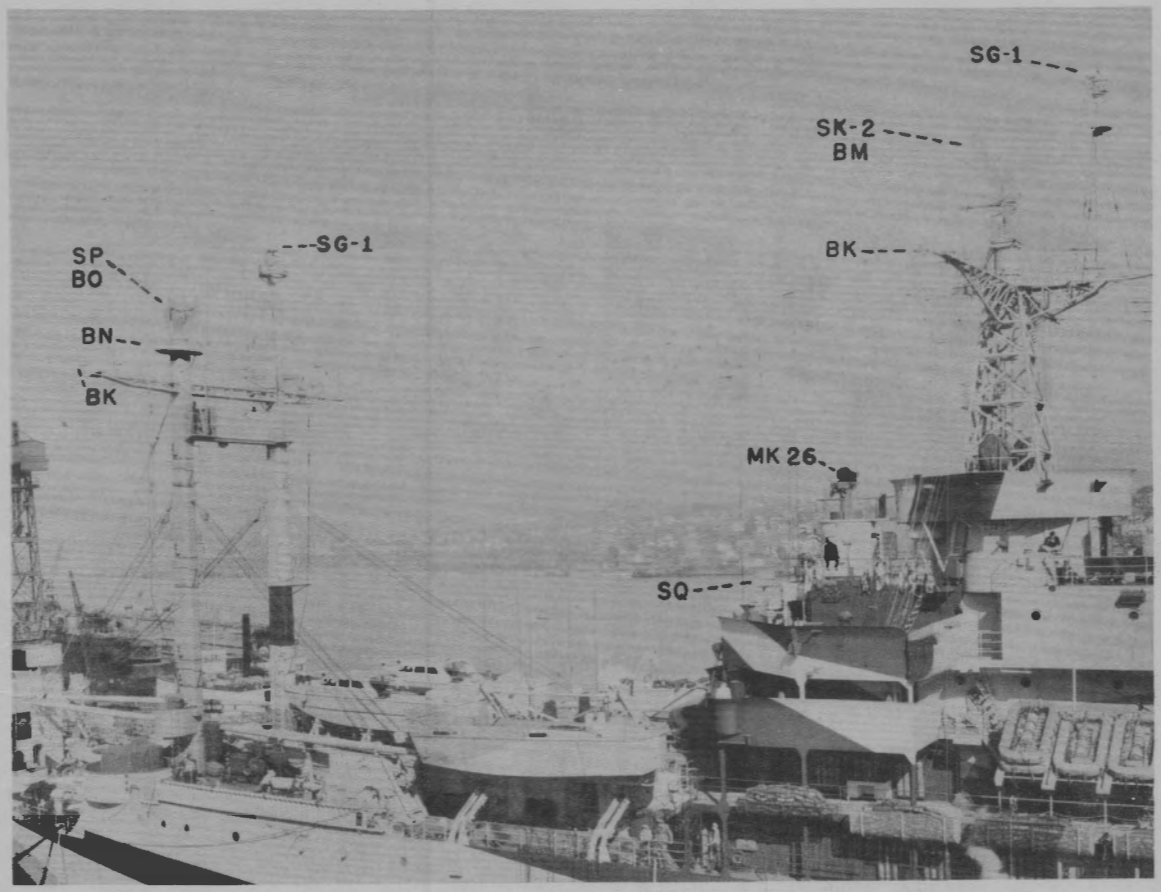


Figure 59—Amphibious force flagship (AGC).

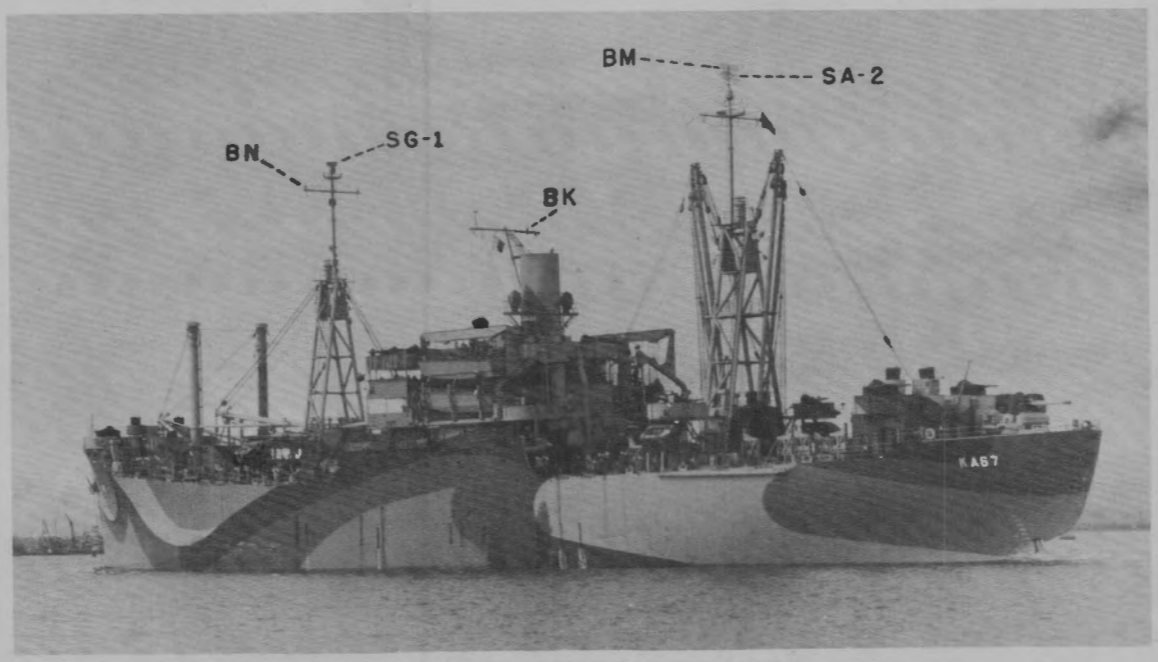


Figure 60—Combat loaded cargo ship (AKA).

RADAR INSTALLATIONS IN SMALL SHIPS AND AUXILIARIES

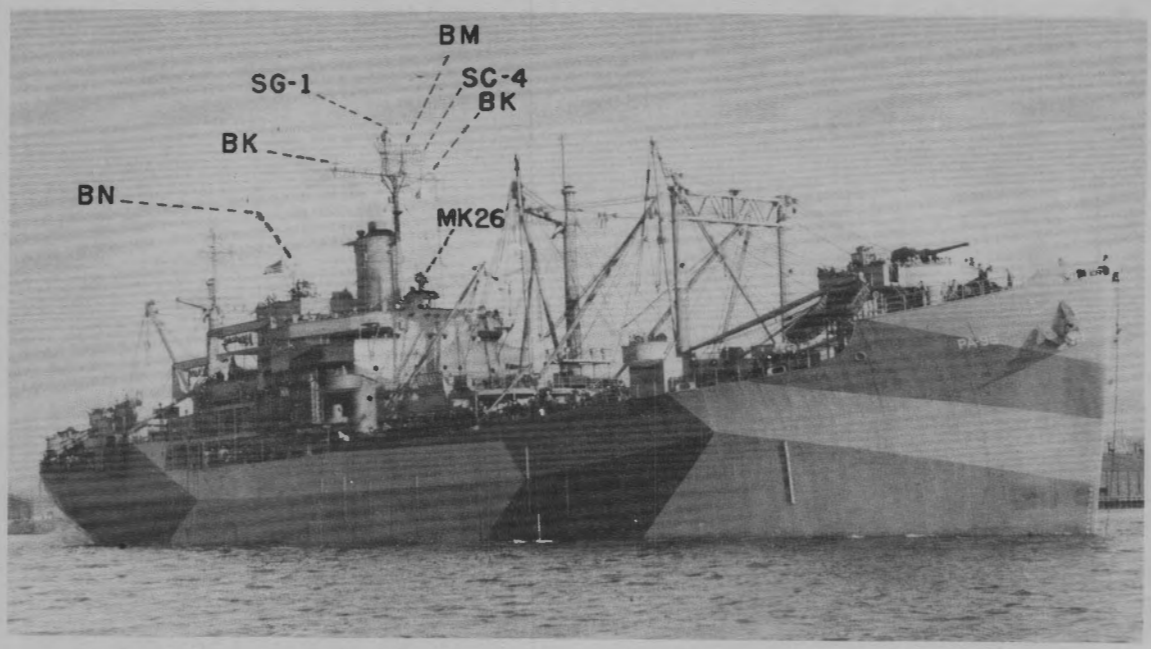


Figure 61—Combat loaded transport (APA).

Figure 62—Motor torpedo boat (MTB).

MODELS SA, SA-2

PURPOSE—Air search

FREQUENCY BAND—P

ANTENNA BEAM WIDTH:

Horizontal	30° (made wider by lobe switching)
Vertical	50°

PULSE DURATION: 5 microseconds

ACCURACY:

Range, ±150 yards on short range scales
Bearing, ±1° with lobe switching on; approximately ±4° on PPI
Altitude, ±2000 feet with calibrated fade chart

INDICATOR:

SA

Type scope	*Range scales*
A	15, 75, 375 miles

SA-2

Type scope	*Range scales*
A	20, 80, 400 miles
7″ PPI	20, 80, 200 miles

MINIMUM RANGE: 1500 yards

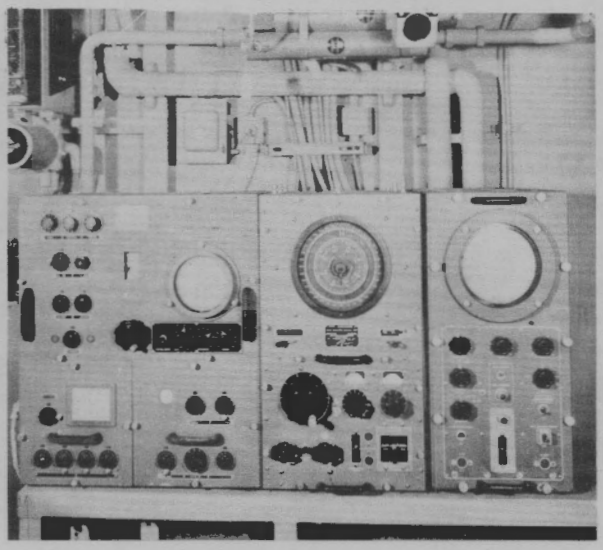


Figure 63—SA-2 operating position.

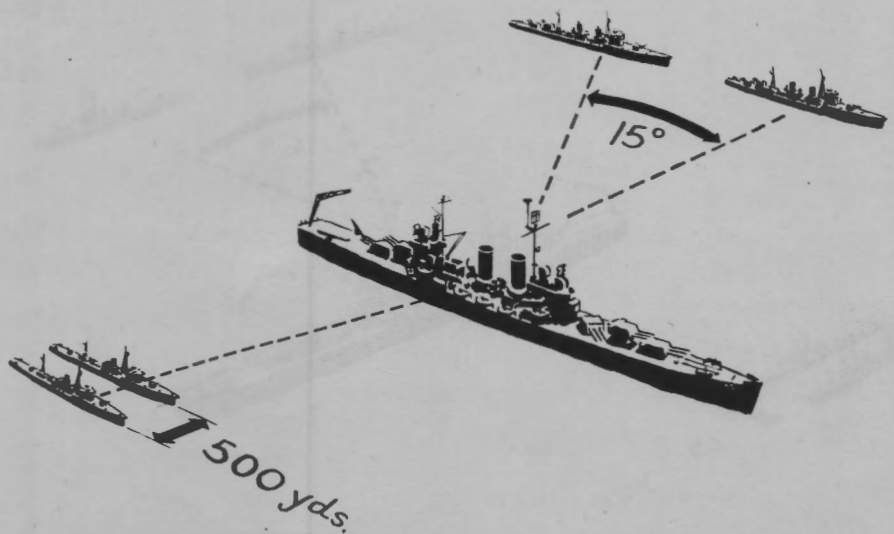


Figure 64—Approximate resolution on short range scale.

MODELS SF, SF-1

PURPOSE—Surface search

FREQUENCY BAND—S

ANTENNA BEAM WIDTH:

Horizontal	12°
Vertical	12°

PULSE DURATION: 1 microsecond

ACCURACY:

Range, ±100 yards on 16,000-yard scale; ±300 yards on 48,000-yard scale
Bearing, ±2°
Altitude, no indication

INDICATOR:

Type scope	*Range scales*
A	0-16,000; 400-48,000 yards
5″ PPI	0-16,000; 400-48,000 yards

MINIMUM RANGE: 400 yards

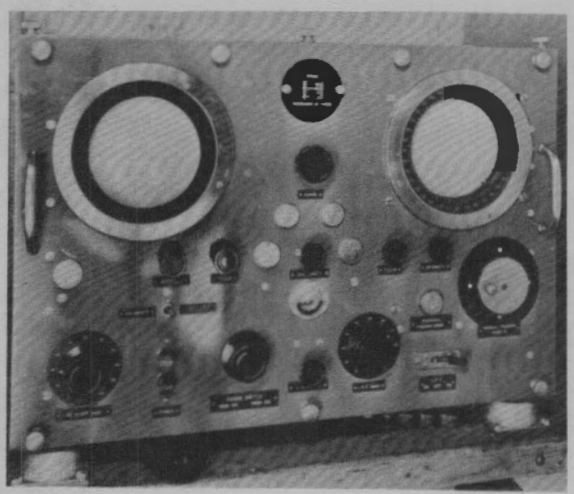


Figure 65—SF operating position.

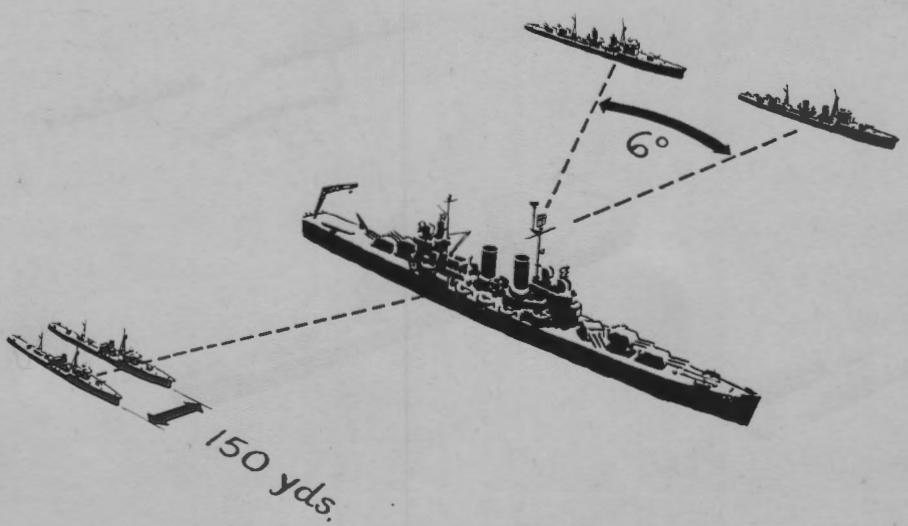


Figure 66—Approximate resolution on short range scale.

MODELS SL-a, SL-1

PURPOSE—Surface search

FREQUENCY BAND—S

ANTENNA BEAM WIDTH:

Horizontal	6°
Vertical	12°

PULSE DURATION: 1.5 microseconds

ACCURACY:

Range, ±100 yards on 20-mile scale
Bearing, ±2°
Altitude, no indication

INDICATOR:

Type scope	*Range scales*
7″ PPI	4, 20, 60 miles

MINIMUM RANGE: 400 yards

Figure 67—SL-1 operating position.

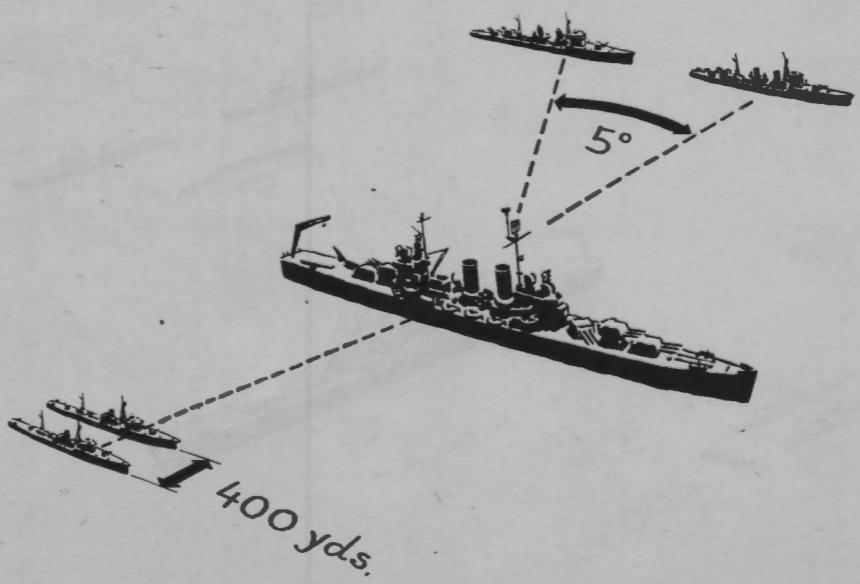


Figure 68—Approximate resolution on 20-mile PPI scale.

MODELS SO, SO-a, SO-13

PURPOSE—Surface search

FREQUENCY BAND—S

ANTENNA BEAM WIDTH:

Horizontal	11°
Vertical	11°

PULSE DURATION: 1 microsecond

ACCURACY:

Range, ±200 yards on 20-mile scale
Bearing, ±2°
Altitude, no indication

INDICATOR:

Type scope	*Range scales*
5″ PPI	4, 20, 80 miles

MINIMUM RANGE: 200 yards

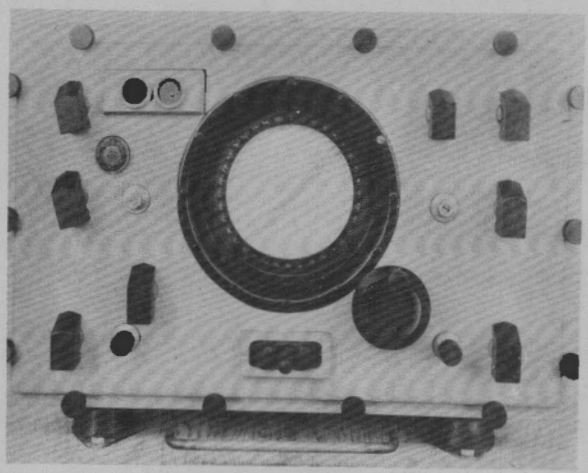


Figure 69—SO operating position.

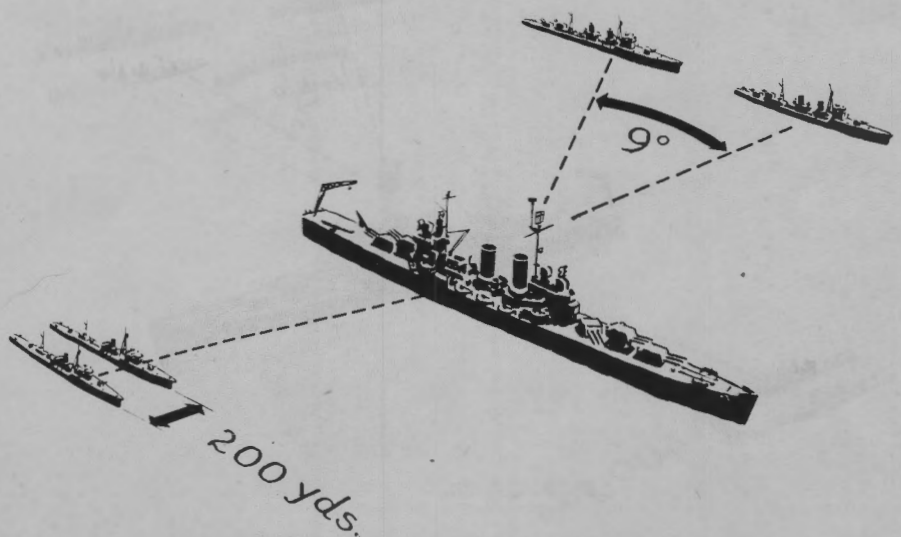


Figure 70—Approximate resolution on 20-mile PPI scale.

MODELS SU, SU-1

PURPOSE—Surface search

FREQUENCY BAND—X

ANTENNA BEAM WIDTH:

Horizontal	3.8°
Vertical	3.8°

PULSE DURATION: 1 microsecond

ACCURACY:

Range, ±30 yards on 4-mi. scale; ±125 yards on 20-mi. scale; ±500 yards on 80-mi. scale
Bearing, ±1°
Altitude, not indicated

INDICATOR:

Type scope	*Range scales*
A	4, 20, 80 miles
5″ PPI	4, 20, 80 miles

MINIMUM RANGE: 300 yards

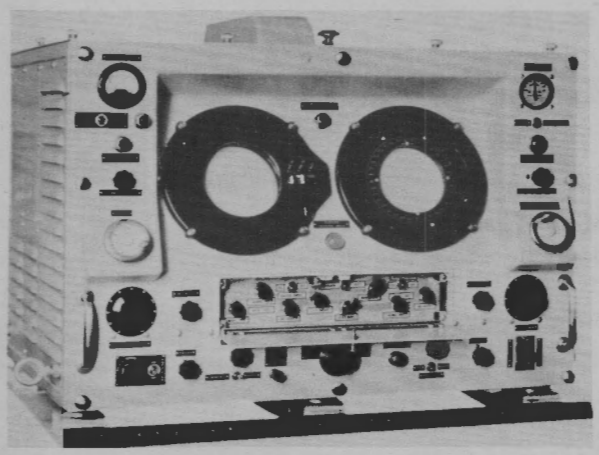


Figure 71—SU operating position.

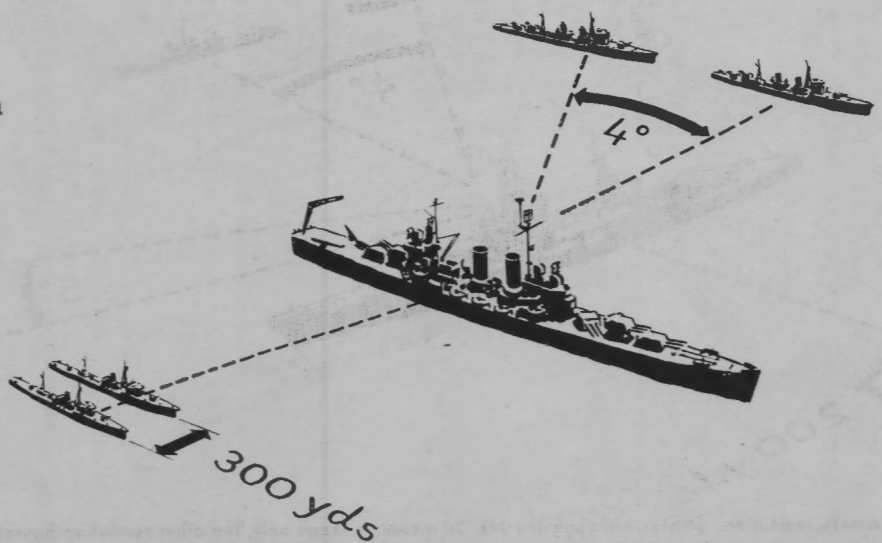


Figure 72—Approximate resolution on 20-mile PPI scale.

MODEL MK 26

PURPOSE—AA fire control for Mk 52 director

FREQUENCY BAND—S

ANTENNA BEAM WIDTH:

Horizontal	7°
Vertical	9°

NOTE: Antenna elevates between —30° and +115°

PULSE DURATION: 0.5 microsecond

ACCURACY:

Range, ±150 yards
Bearing, not indicated
Altitude, not indicated

INDICATOR:

Type scope	*Range scales*
J	12,000, 30,000 yards

Measures range only. Targets are tracked optically in bearing and elevation.

MINIMUM RANGE: 400 yards

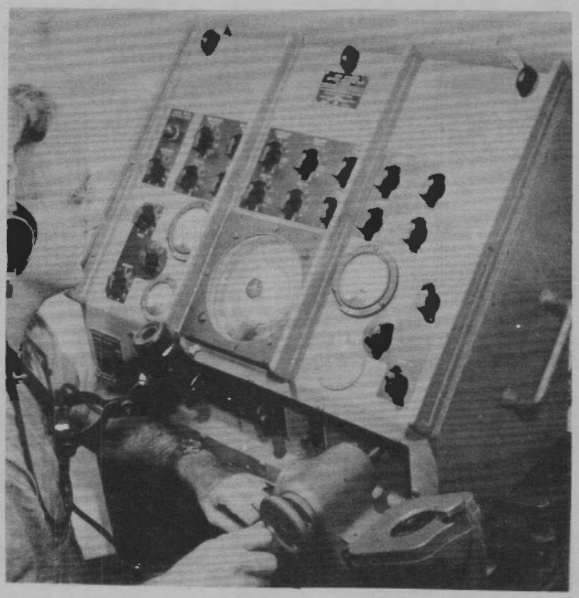


Figure 73—MK 26 operating position.

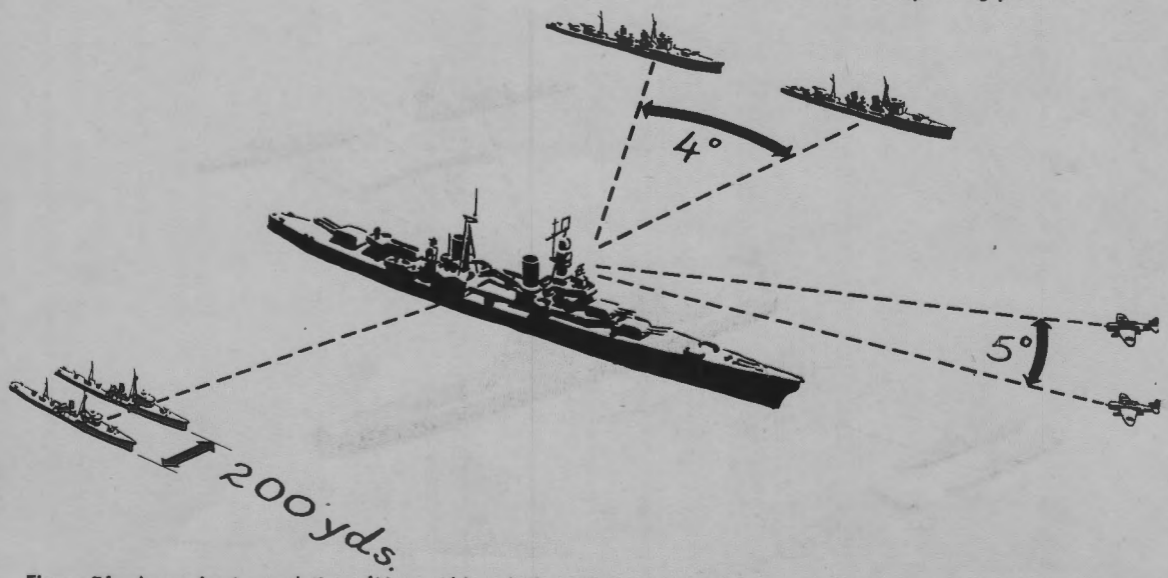


Figure 74—Approximate resolution. (Note: Although the MK 26 measures range only, the other resolution figures indicate the zone of confusion possible with multiple targets.)

RADAR INSTALLATIONS IN SUBMARINES

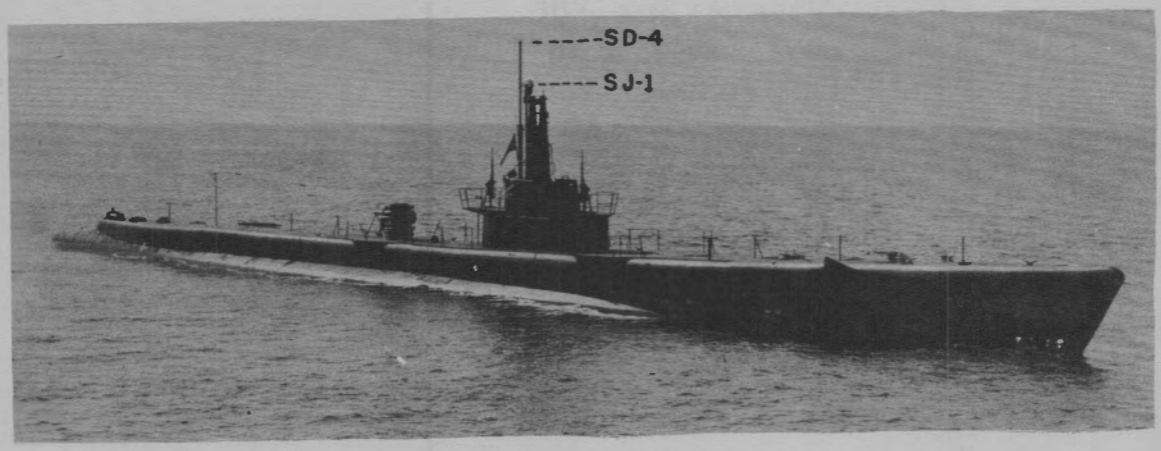


Figure 75—Submarine (SS).

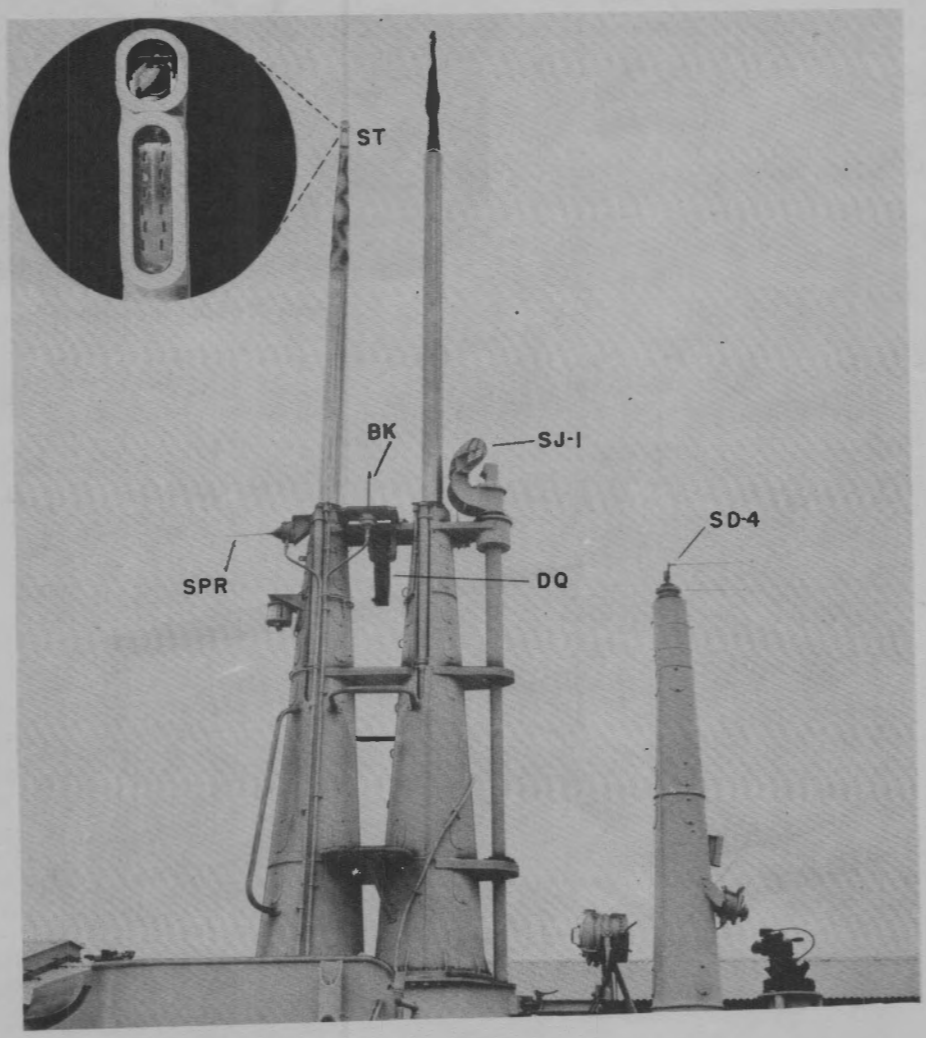


Figure 76—Close-up of submarine antennas.

MODELS SD-a, SD-2, SD-4

PURPOSE—Air warning

FREQUENCY BAND—VHF

ANTENNA BEAM WIDTH:

Horizontal	circular
Vertical	circular

PULSE DURATION: 7-10 microseconds

ACCURACY:

Range, ±1000 yards
Bearing, no indication
Altitude, no indication

INDICATOR:

SD-a, SD-2

Type scope	*Range scale*
A	30 miles

SD-4

Type scope	*Range scales*
A	15, 60 miles

MINIMUM RANGE: 2000 yards

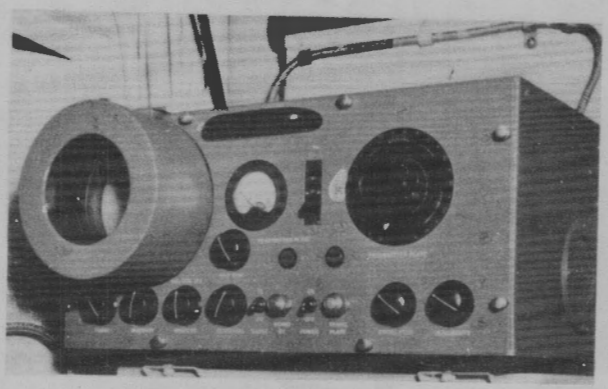


Figure 77—SD operating position.

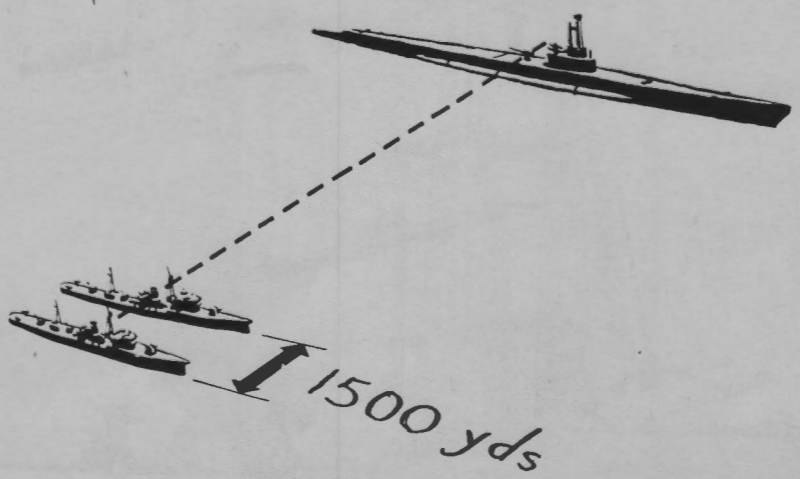


Figure 78—Approximate range resolution. Since the antenna radiates equally on all bearings, there is no bearing resolution.

MODELS SJ-a, SJ-1

PURPOSE—Surface search

FREQUENCY BAND—S

ANTENNA BEAM WIDTH:

Horizontal	9°	(made wider by lobe switching)
Vertical	29°	

PULSE DURATION: 1/4 microsecond

ACCURACY:

Range, ±15 yards ±0.1% of actual range
Bearing, ±1/4° with lobe switching on; approximately ±2° from PPI
Altitude, no indication

INDICATOR:

Type scope	*Range scales*
A	10, 30 miles
5" PPI	4, 10, 40 miles
R	2500 yards

MINIMUM RANGE: 250 yards

Figure 79—SJ operating position.

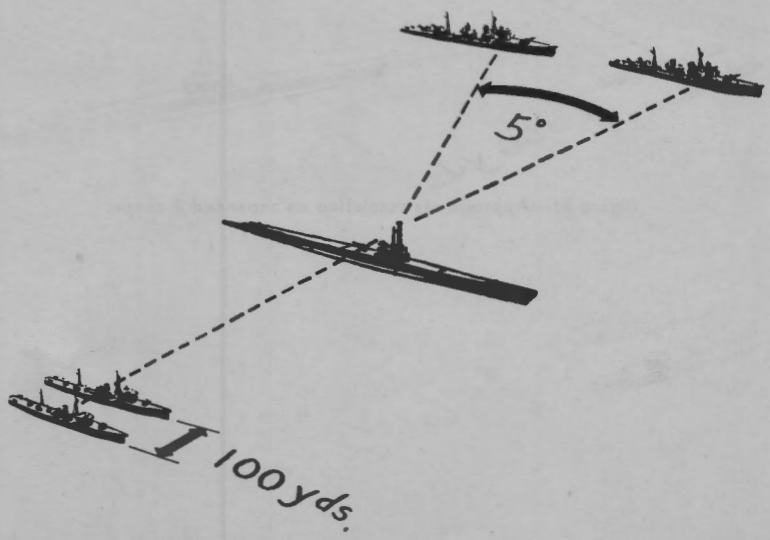


Figure 80—Approximate resolution on precision scope.

MODEL SS

PURPOSE— Surface search

FREQUENCY BAND—X

ANTENNA BEAM WIDTH:

Horizontal	2.6°
Vertical	16°

(made wider by lobe switching)

PULSE DURATION: 0.5 microsecond

INDICATOR:

Type scope	*Range scales*
A	4, 10, 20, 80 miles
B	4000 yards × 30° sector
5" PPI	4, 10, 20, 80 miles

MINIMUM RANGE: 250 yards

ACCURACY:

Range, ±15 yards ±0.1% of range scale
Bearing, ±¼° with lobe switching on
Altitude, no indication

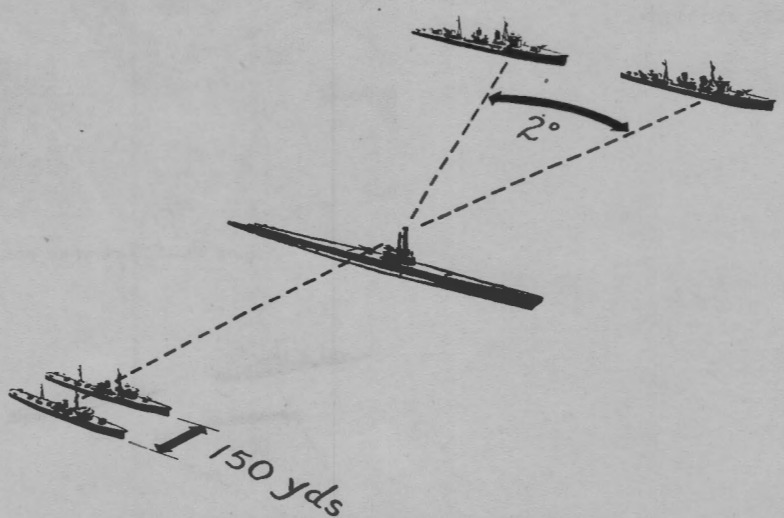


Figure 81—Approximate resolution on expanded B scope.

MODEL ST

PURPOSE—Periscope surface search

FREQUENCY BAND—X

ANTENNA BEAM WIDTH:

Horizontal	30°
Vertical	10°

PULSE DURATION: 0.3 microsecond

ACCURACY:

Range, ±15 yards ±0.1% of actual range.
Bearing, optically determined. Approximately ±5° by radar.
Altitude, not indicated.

INDICATOR:

Type scope	*Range scales*
A	10, 30 miles
R	2500 yards

NOTE: ST uses indicators furnished with either the SJ or SS. When it is desired to use ST, SJ is switched off and ST switched on. Set is designed for use at periscope depth.

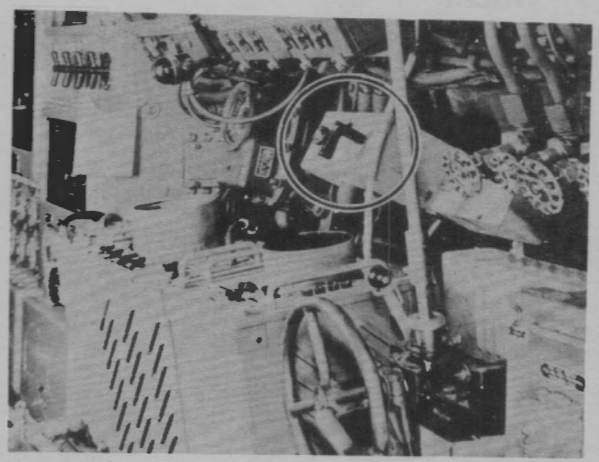


Figure 82—ST operating position. Selector switch for connecting SJ indicators to ST radar is encircled.

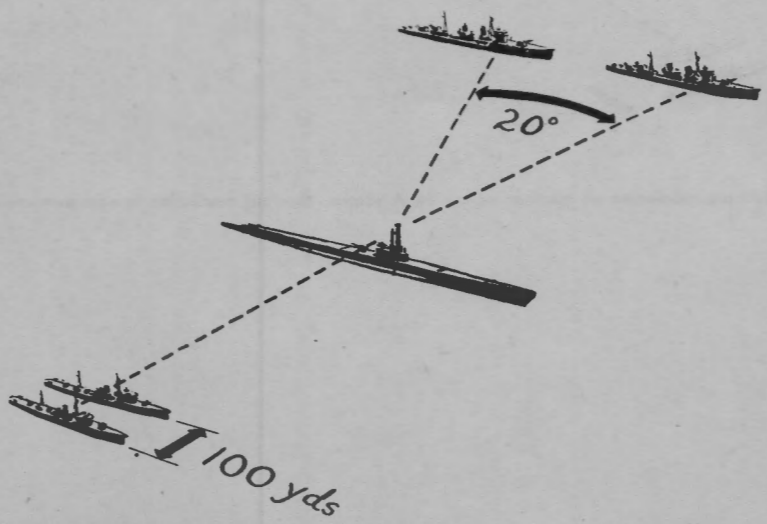


Figure 83—Approximate resolution. ST cannot measure bearing accurately, but because of wide beam, two targets within approximately 20° will cause confusion.

MODEL SV

PURPOSE—Air search

FREQUENCY BAND—S

ANTENNA BEAM WIDTH:

Horizontal	5.5°
Vertical	60°

PULSE DURATION: 1 microsecond

INDICATOR:

Type scope	*Range scales*
A	10, 30 miles
5″ PPI	4, 10, 40 miles

MINIMUM RANGE: 400 yards

ACCURACY:

Range, ±15 yards ±0.1% of actual range
Bearing, ±1°
Altitude, not indicated

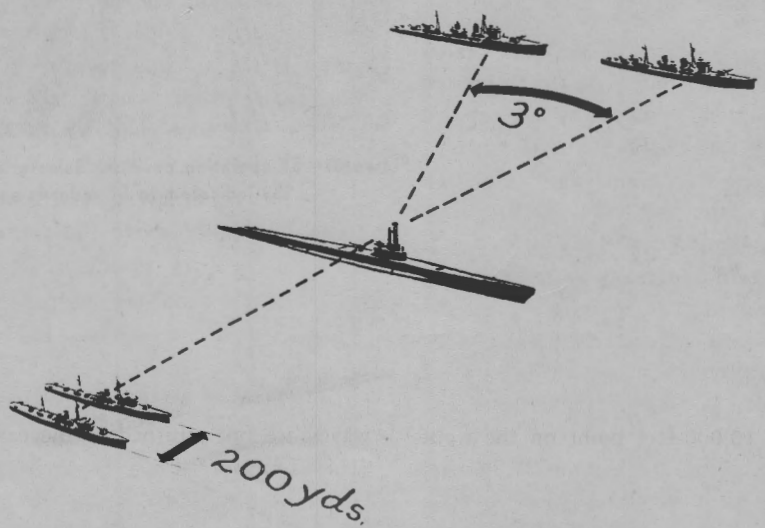


Figure 84—Approximate resolution at medium range on A scope. Bearing resolution is approximately 5° on PPI.

CHAPTER IV

LIMITATIONS IMPOSED ON RADAR BY EXTERNAL FACTORS

A. Propagation of radio-frequency energy:

Antenna height; bending of radio waves; reflection of radio waves from the sea; antenna pattern; attenuation of transmitted pulse; type of target.

B. Nonstandard propagation of radio waves—trapping:

General features; effect on radar performance; meteorological factors that cause trapping; prediction of nonstandard propagation.

C. Weather:

Roll and pitch of ship; sea return; formation of ice on antenna; storms; atmospheric noise.

A. PROPAGATION OF RADIO-FREQUENCY ENERGY

1. General.

If it is assumed that radio waves travel along perfectly straight paths, the curvature of the earth prevents these straight rays from striking objects that are beyond the horizon. If the height of the antenna is increased, the point at which the lowest radiated ray is tangent to the curve of the earth is made more remote. That is, the horizon is extended. An object beyond the horizon can be seen if it is high enough that the ray tangent to the earth can strike it.

Figure 85 shows a nomogram that correlates radar antenna height and target altitude with the maximum range of the target as determined by the optical horizon. This chart is reasonably accurate for estimating radar ranges, but since changing propagation conditions may have considerable effect on the range of a radar, the nomogram cannot be relied on implicitly. For example, if the radar antenna is 100 feet above the water, and it is desired to find the maximum range at which a group of planes flying at 10,000 feet can be detected, a line is drawn as in figure 85 between the 100-feet point on the left vertical line and the 10,000-feet point on the right vertical line. The intersection on the middle vertical line indicates that the planes could be detected at a maximum range of 134 miles. However, this is no definite indication that the planes will be detected at this range; it simply shows that the geometry of the line of sight from the antenna is such that the planes *may* be detected at that range.

Radio waves, like light waves, must pass through the atmosphere to get from one place to another. The characteristics of the medium through which the waves pass affect the manner of their transmission. Thus, although it is sometimes assumed that both light and radio waves follow perfectly straight paths, the properties of the atmosphere are such that the waves are made to follow curved paths. One very common effect of the bending that light waves experience in passing through the atmosphere is apparent at sunrise and sunset. At this time the sun is very low, so that none of its light would be visible if the rays followed straight paths, but because the red components of the light are bent down to earth the sky is brightly colored. The propagation of radio waves is affected, then, by: the composition of the atmosphere, which controls the amount of bending, or *refraction,* that the waves experience in their passage; the *diffraction* that bends the waves over the horizon to some extent; and by the *reflection* of the radio waves from the surface of the sea. Other factors that affect propagation of radar pulses are the nature of the antenna pattern, the attenuation of the radar waves in their passage through the atmosphere, and the size and character of the target that the pulses strike.

The Heaviside layers, which are in the ionosphere 30 to 200 miles above the earth, reflect long-wave radio energy back to the earth, and so exert considerable effect on the propagation of frequencies below about 40 megacycles. However, the Heaviside layers are penetrated by the high frequencies used in radar and most VHF communications, so that these waves are not returned to the earth. Therefore the Heaviside layers have no appreciable effect on the propagation of radar pulses.

2. Bending of Radio Waves.

The quantity that indicates the degree of bending from a straight-line path is called the *index of refraction.* Refraction occurs whenever there is a *change* in the medium through which the waves are passing, as at the boundary between two substances. The measure of the bending that occurs at such a boundary is indicated by the change of index of refraction from one substance to the other. In the interior of a homogeneous material, in which the index of refraction is constant, light waves or radio waves travel in a straight line.

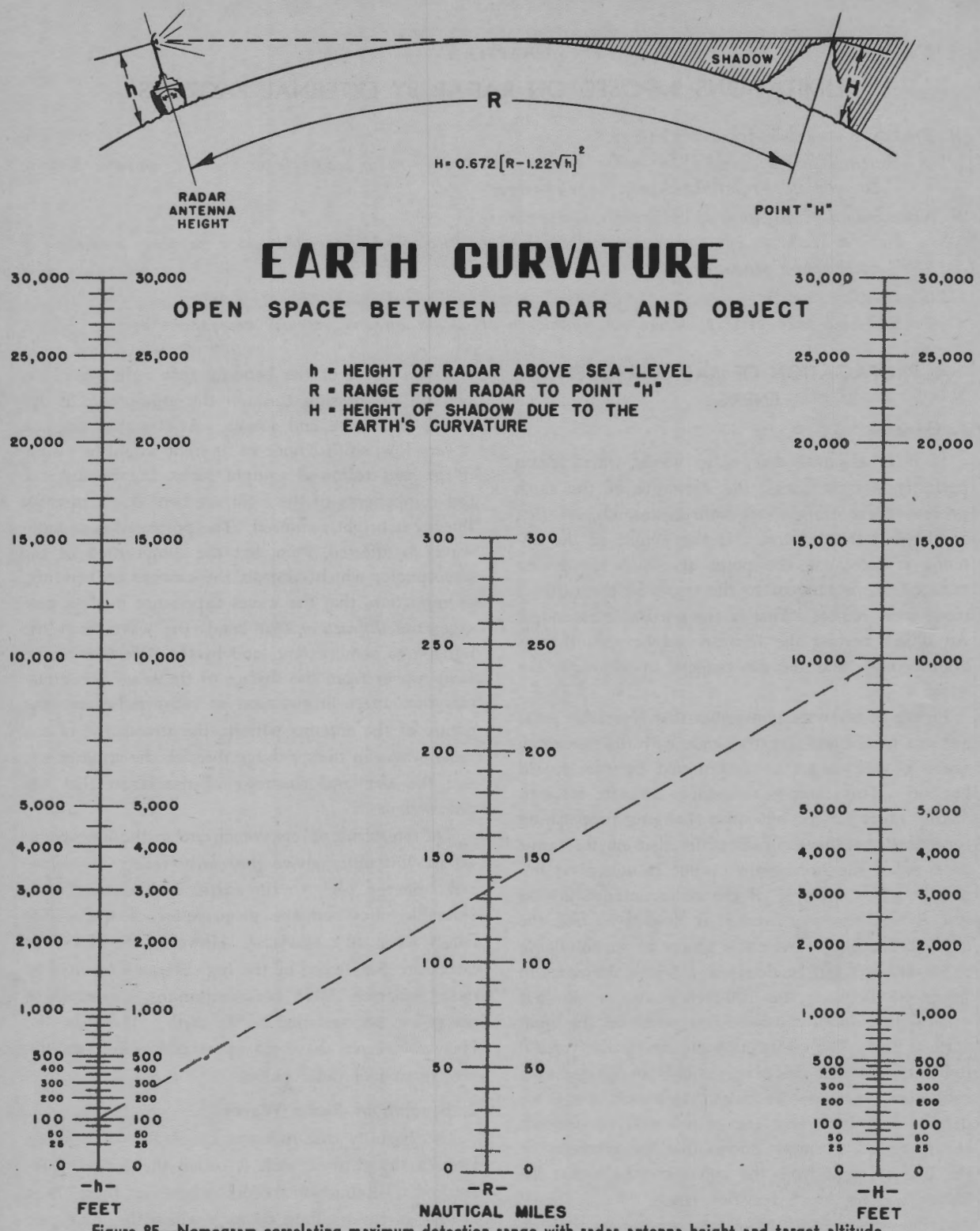


Figure 85—Nomogram correlating maximum detection range with radar antenna height and target altitude.

Basic to the understanding of the propagation of radio waves through the atmosphere is the fact that the atmosphere is not a homogeneous medium. The changeable characteristics of the atmosphere are temperature, pressure, and moisture content, and these factors vary with altitude. However, the change in characteristics of the atmosphere from one level to the next is small, so that a radio wave is refracted only a small amount in passing up through the atmosphere. Nevertheless, refraction is of great importance in radar operation and communications at frequencies above 30 megacycles.

Since the change in the physical properties of the atmosphere is normally gradual and continuous, the index of refraction also changes gradually with increasing height. Consequently, there is no sudden change in the direction of the radar waves; rather the change in direction is gradual and continuous. Radio waves passing through the lower atmosphere are usually bent *downwards.*

In order to establish a reference for the purpose of investigating the effect of the atmosphere on propagation, a so-called standard atmosphere has been postulated. The standard atmosphere is likely to be found in nature when the air is well mixed so that no unusual temperature or humidity gradients can exist. In the standard condition the temperature and mosture content of the air decrease uniformly with height. However, this standard atmosphere is not necessarily the normal atmosphere at any particular location. Above 10,000 or 12,000 feet the atmosphere is almost always of standard composition, but non-standard propagation conditions may often exist in the lower atmosphere. The conditions that lead to such nonstandard propagation and the effects on radar operation are discussed in section B of this chapter; the discussion in section A is based on standard propagation.

Since the water vapor in the atmosphere bends radio waves almost twenty times more than light waves, the distance to the apparent horizon for a radar set is approximately 15% greater than the distance to the optical horizon. Thus, in figure 86A the optical line of sight from point (1) is tangent to the earth at point (2), while the radar ray, which is more curved, is tangent to the earth at point (3). In many cases it is more convenient to draw the radar rays as straight lines as a means of simplifying the picture. It has been found that if the radius of the earth is considered to be 4/3 of the actual radius, then the radar rays may be drawn as straight lines when propagation conditions are standard, as in figure 86B. Often in plotting fade charts the antenna pattern is plotted on rectangular coordinates, in which the earth is assumed to be flat. The result of this assumption is that both the optical and radar rays appear to curve upward, as in figure 86C. The shape of the lobe of the radar antenna under these three conditions is shown in each part of figure 86. Note that the shape shown in A is true, except for the exag-

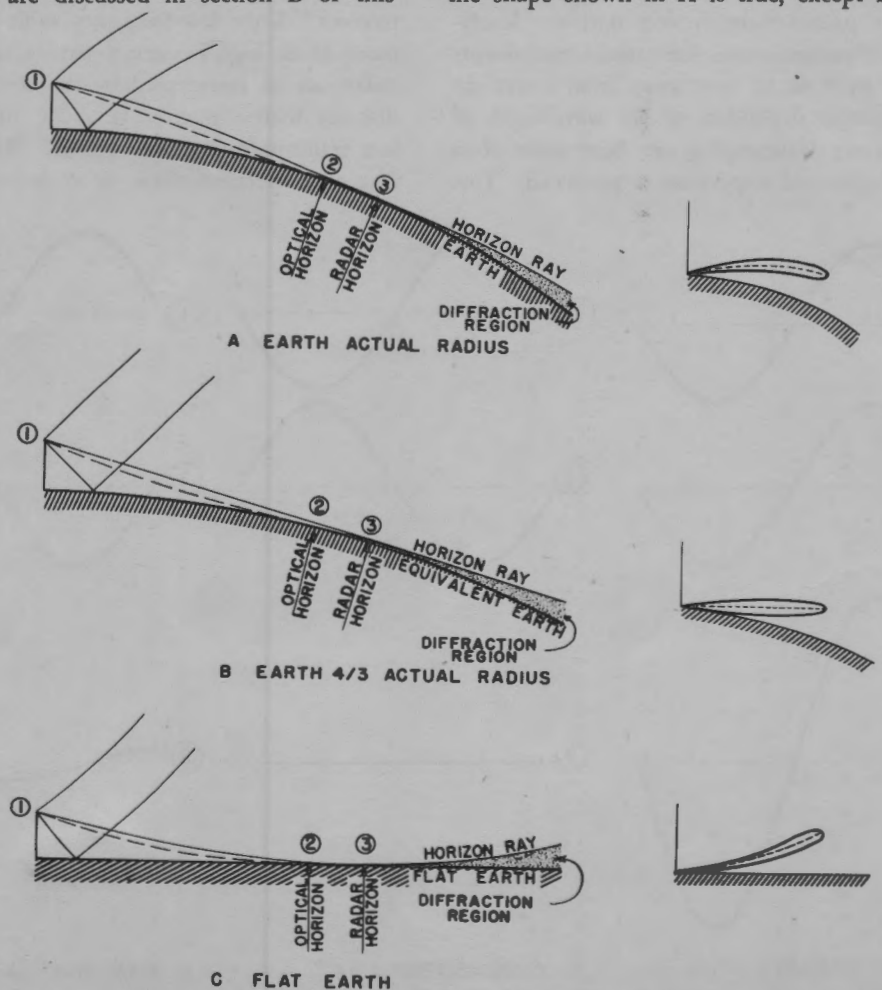


Figure 86—Comparison of radar horizon with optical horizon.

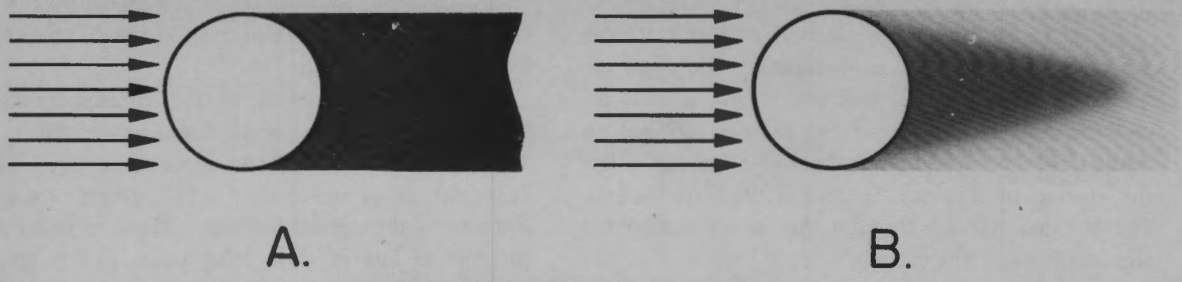


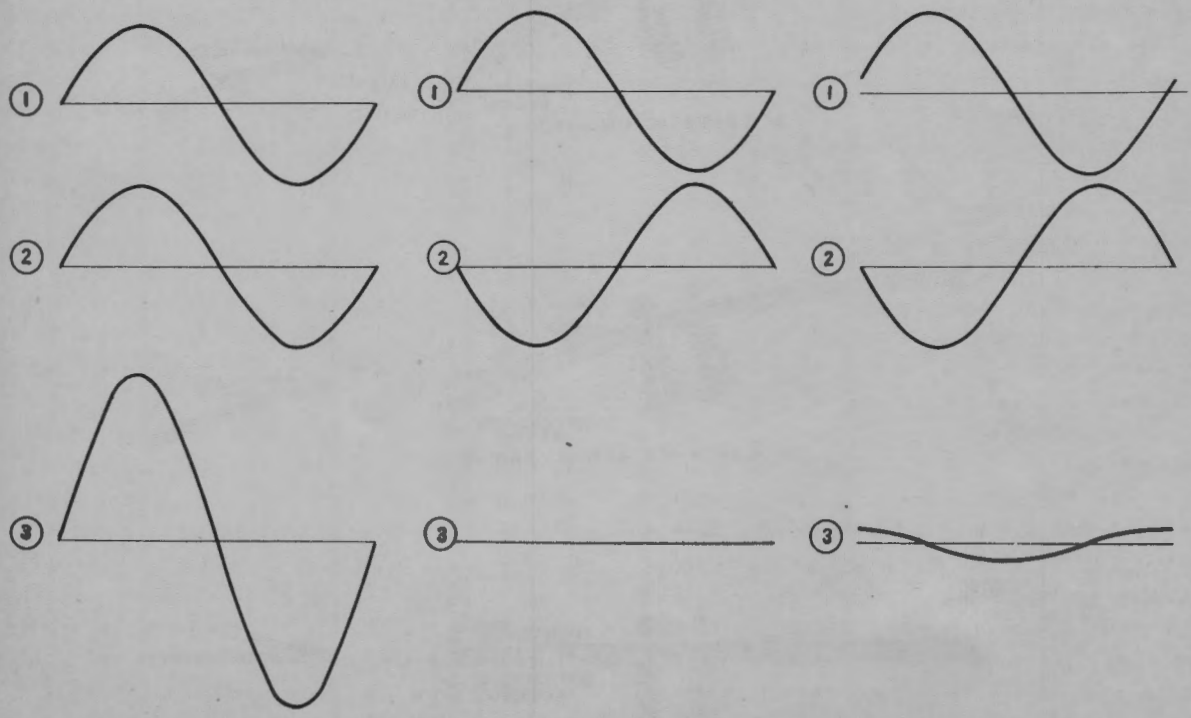
Figure 87—Effect of diffraction on shadow.

geration of the vertical dimensions, while in B and C the lobes show the distortion occasioned by changing the coordinate system for convenience in plotting. All three diagrams, however, are exactly equivalent, and they show the same thing.

Under standard conditions, radar pulses cannot penetrate the region which lies below the horizon ray since the radiated energy cannot enter this area either by bending or by reflection from the earth. However, measurements indicate that some of the pulse energy does enter this region because of *diffraction* of the energy around the earth's curvature.

Diffraction of radio waves can perhaps be explained most simply by discussing its effect on light. When white light is passed through very narrow, closely-spaced slits, diffraction causes the various components of the white light to be bent away from a straight path by an amount dependent on the wavelength of the light. Long wavelengths are bent more than short wavelengths and a spectrum is produced. This same bending effect can be observed in shadows cast by sunlight. The light rays from the sun are essentially parallel, yet a shadow of a ball does not have sharp clear edges, as in figure 87A, because of diffraction. When the rays pass close to the surface of the ball, they are bent inward slightly and so they penetrate the shadow, partially illuminating its edge, as in figure 87B. Since the wavelengths of the radio waves used in radar are much longer than those of visible light, the amount of bending caused by diffraction is also greater.

Although the radar energy diffracted around the curve of the earth usually is too weak to produce usable echoes, it can still be detected by a suitable receiver. Since low-frequency radio waves are bent more than high-frequency waves, a low-frequency radar can be intercepted by the enemy at a greater distance than a microwave radar, provided the two sets transmit comparable power. The principal effect of diffraction, then, is to extend the range of



A. PHASE RELATION = 0° B. PHASE RELATION = 180° C. PHASE RELATION = 170°

Figure 88—Addition of sine waves.

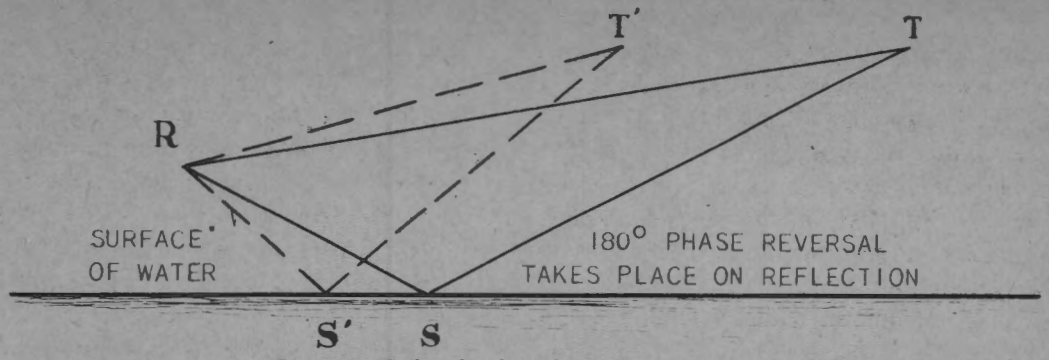


Figure 89—Paths taken by radiation in reaching target.

possible interception of radar transmitted pulses by enemy surface vessels beyond the radar range.

3. Reflection of Radio Waves from the Sea.

The pulse of energy transmitted by a radar is carried through space by an alternating electromagnetic field that moves at the speed of light. At any point in space, the magnitude of the field varies from some maximum positive value through zero to the same maximum value in the negative direction, and then through zero in the positive direction again as the pulse of energy travels past the point. This variation takes place at a rate of several hundred million times per second during the radar pulse. It is convenient to represent such an alternating field by a sine curve, since the time-variation of the field carrying the pulse energy is of this character.

If energy arrives at a point in space by following two different paths, the resultant field at that point will be determined by the contributions from each of the two paths. Since both fields alternate at the same rate, the resultant field is determined not by simple addition, but by the combination of two sine waves.

If two sine waves vary exactly together as ① and ② in figure 88A, they are said to be *in phase*, or to have a phase relation of 0°. Since waves that bear this relationship always rise to maximum and pass through zero at exactly the same time, they add at every instant, so that one wave reinforces the other, making their sum the wave shown in figure 88A at ③. If the two sine waves are in opposition, as ① and ② in figure 88B, they are said to be 180° out of phase. Since wave ① always increases in one direction at the same rate and at the same time that wave ② increases in the other, one wave cancels the other, and their sum at all times is zero, as indicated by the horizontal line in figure 88B ③. If the waves are not a full 180° out of phase, as in figure 88C, partial cancellation takes place, depending on the phase relation, and the resultant wave is small.

Unless the radar antenna has a narrow beam that can be elevated, some of the radiated energy must hit the water and be reflected. In most cases, then, energy can arrive at a target T by both the direct path RT and the path RST involving reflection from the sea (figure 89). The nature of the reflection from the sea is such that the reflected wave is 180° out of phase with the incident wave. This change coupled with the fact that the two paths are not of the same length causes a phase difference between the two paths. Since this phase difference varies with the position of the target relative to the radar antenna, the strength of the energy at the target also varies with the target's position. For example, the phase relation of the two waves that arrive at point T in figure 89 is such that the fields reinforce, while at T' the fields cancel. If all points in space are considered, it will be found that many points exist at which complete cancellation occurs, and many other points where the reflected and direct waves reinforce. The area adjacent to a line joining the points of cancellation is called a *null* because echoes cannot be returned from targets within this area. Thus, the result of reflection of the radar pulse from the sea is to break the vertical antenna pattern into many rather narrow lobes which are separated by the nulls.

For a given frequency, the angular separation of the lobes and the height of the lobe closest to the surface of the water are dependent on the height of the antenna above the water. The higher the antenna is mounted, the closer the lowest lobe will be to the surface of the water, and the lobes will be more closely spaced. If the radar frequency is low and the antenna is mounted close to the surface of the water, the nulls will be rather wide, making several blind areas in the radar coverage. It would appear possible for a plane with a suitable intercept receiver to fly down a null by keeping in the region of minimum signal strength, thus remaining undetected until it reached a very close range. Tests in which evasive tactics of this sort have been tried were not highly successful, since it is very difficult to stay within the null area. The Japanese evidently have attempted this maneuver with partial success, although it is believed that they do not carry intercept receivers speci-

fically for this purpose. Since radar antennas are usually mounted reasonably high, the extent of the nulls is small, making it still more difficult for the plane to remain undetected for long.

The lobe pattern is affected by the radio frequency transmitted as well as by the height of the antenna. At very high frequencies, interference produces many narrow lobes that are separated by small angles. For a given antenna height, the lowest lobe will be closer to the water for a high frequency than for a low frequency. Compare figure 90A with figure 90B.

Below the lowest lobe of the antenna pattern is a region of practically complete cancellation. This condition prevents the air search radars, which are operated at a relatively low frequency, from detecting either surface vessels or low-flying airplanes at long ranges under standard weather conditions. Therefore, radar equipment which is to be used for surface search employs very high frequencies, usually in either the *S* or *X* band because the lowest lobe comes much closer to the line-of-sight boundary.

The protection against torpedo plane attack afforded by the air search radar usually is very poor. By the time the air search radar detects aircraft flying fifty or a hundred feet off the water, the plane has closed to such a range that there is little opportunity to intercept or to bring guns to bear. This serious limitation of low-frequency radar may be remedied partially by installing the antenna in the highest possible position on the ship. However, chief reliance for the detection of very low-flying airplanes at present must be placed on the low-angle search radar, such as the *SM* and *SP*, or on surface search radar. The *SX* general purpose radar should be very helpful for this application when the set becomes available.

In addition to producing many lobes and nulls in the radiation pattern, reflection of radar pulses allows the maximum range of detection to be nearly doubled. This increase results purely from the reflection of energy from the water; no change in characteristics of the radar is required. If no water reflection takes place, only one possible path, the direct one, exists between the radar and the target. When the target is near the maximum of a lobe, the pulse can reach the target by two paths and the echo can return to the radar antenna along the same two paths. Since more of the pulse energy can get to the target by two paths than by one, the echo is stronger, and a larger fraction of this stronger echo is returned to the radar by the two paths than if there were no reflection taking place from the water. As a result of this phenomenon, the coverage of the SM radar is approximately like that shown in figure 91. When the antenna beam is horizontal or tilted up by a small angle, some of the radiated energy strikes the water, and targets can be detected out to approximately 80 miles. However, when the beam is elevated so high that none of the energy is reflected from the water, targets can be detected only out to approximately 43 miles.

The phenomenon of producing lobes as a result of water reflection is not restricted only to radar.

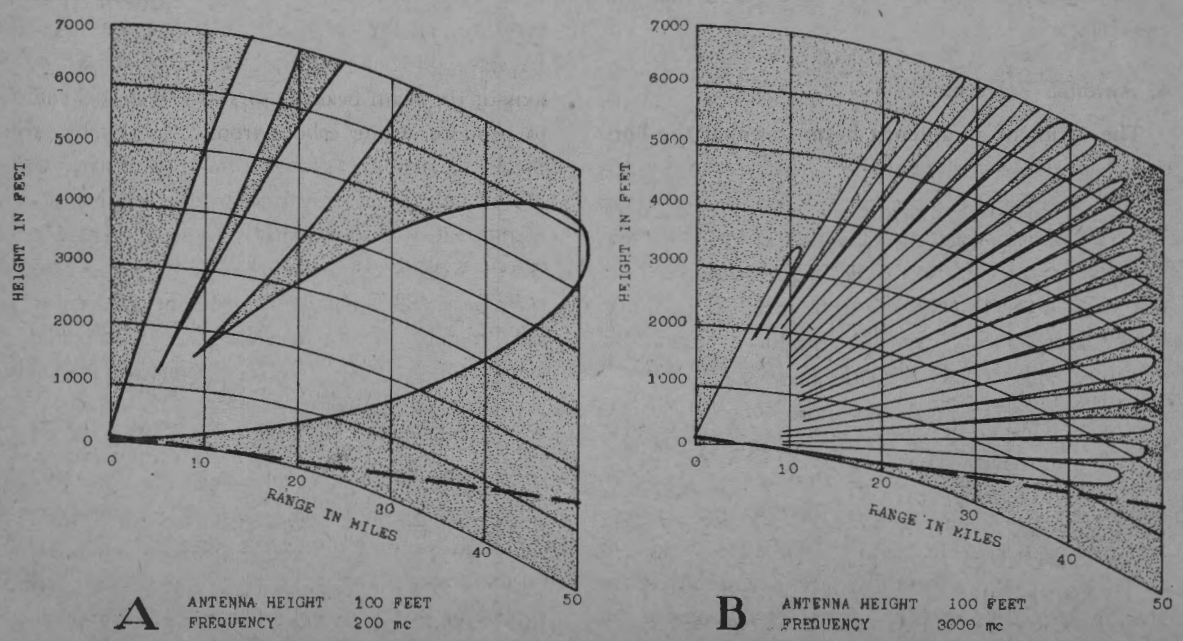


Figure 90—Lobe diagrams under standard atmospheric conditions.

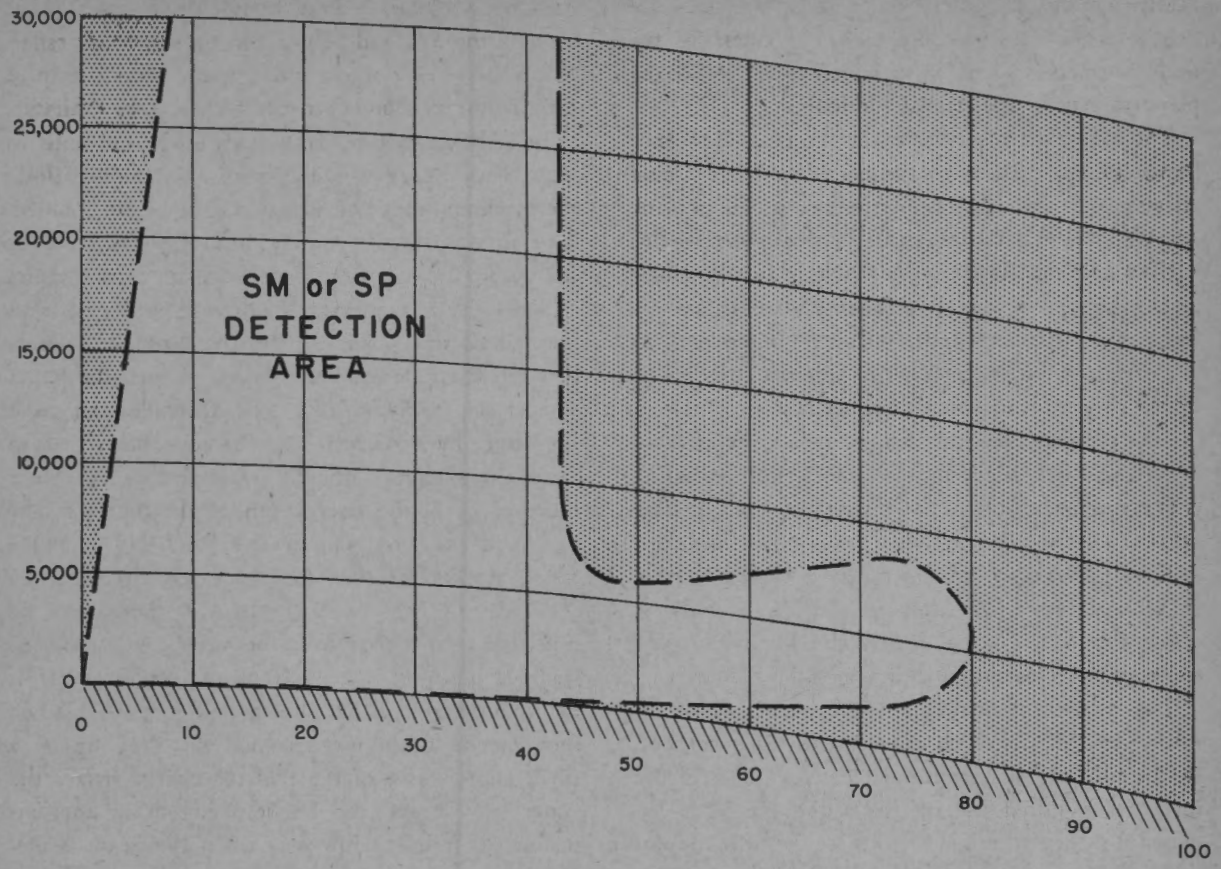


Figure 91—Effect of water reflection on radar coverage.

It must be realized that VHF communications energy also is confined to lobes such that at many places in space there will be nulls, or dead spots, in which communications will be very difficult if not impossible.

4. Antenna Pattern.

The width of an antenna beam in either the horizontal or vertical dimension is determined by the width and height of the radar antenna in *wavelengths*. Thus at long wavelengths, the directivity of the antenna is restricted by practical limitations on the maximum physical size that can be installed in a ship. Very narrow beams can be produced practically, therefore, only at very high frequencies.

The sharper the beam, the more concentrated the energy and therefore the greater the range obtainable with a given amount of transmitted power. The narrower the beam, the greater the bearing accuracy and bearing resolution possible. Thus low-frequency air-search radars inherently have relatively poor bearing accuracy and bearing resolution because the antenna beam cannot be made very sharp.

Although a radar antenna is highly directional, not all of the radiated energy is confined to the principal beam. Some energy, usually one per cent or less of the main lobe, is radiated in all directions, especially by the air search radar antennas (fig. 92). In spite of the fact that the radiation far off the axis of the main beam is so small, it is still sufficient to produce strong echoes from large nearby targets. If several large ships are within approximately a mile of the radar, they may produce saturation echoes no matter where the antenna is trained. These strong echoes will then prevent the small echoes from aircraft or small surface craft from being seen at very short ranges. If the receiver gain is decreased, the echoes from the small targets may be lost, while those from the large ships or nearby land are simply reduced to a value somewhat below saturation. Sensitivity-Time Control (*STC*), a circuit that automatically reduces receiver gain during the first few thousand yards of the sweep and then returns it to normal, should be very useful in minimizing the echoes returned in side lobes. However, in a partially land-locked harbor, the echoes returned from

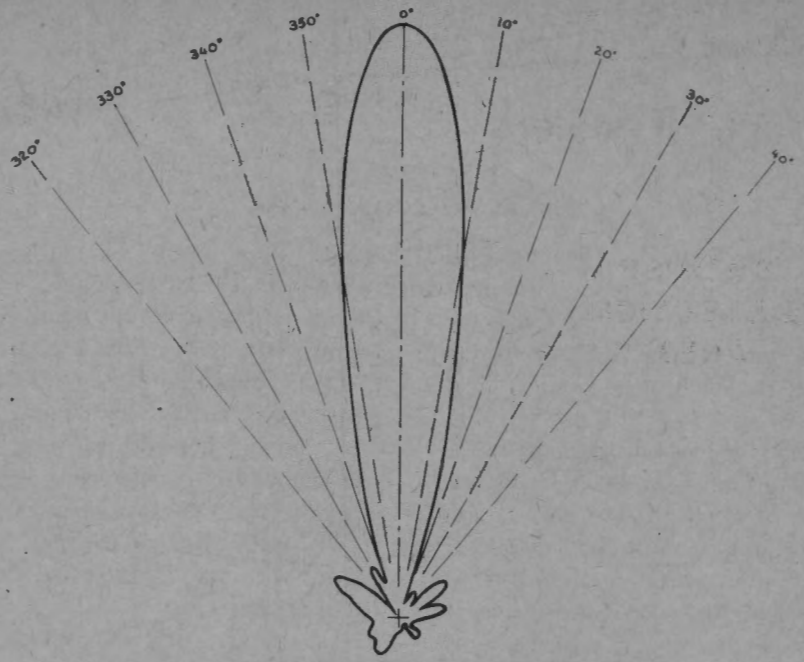


Figure 92—Radiation pattern of air search radar antenna.

the land may be so strong that nearly the whole screen may be covered with land echoes. These echoes may be so strong that STC will be of little assistance, and reliance must be put in other circuits to enable the operator to read through the clutter.

In some cases it is desired to produce an especially broad beam in the vertical direction so that a large area can be scanned thoroughly. An antenna has been developed for this purpose which produces what is called a cosecant squared beam in the vertical direction. The horizontal beam width may be made as narrow as practical. The outstanding feature of a beam of this type is that the field intensity is essentially uniform along any horizontal line, such as *A–B* or *C–D* in figure 93. As a result, an airplane detected at *D* can fly to *C* without the echo amplitide increasing appreciably. Such a beam is useful where it is desired to know quickly whenever an airplane, irrespective of height, enters the area under search. A beam of this sort is desirable also because it minimizes ground and sea clutter on shipboard installations. However, in airborne radars that use this type of antenna beam the sea return may extend many miles beyond the limit observed on other sets.

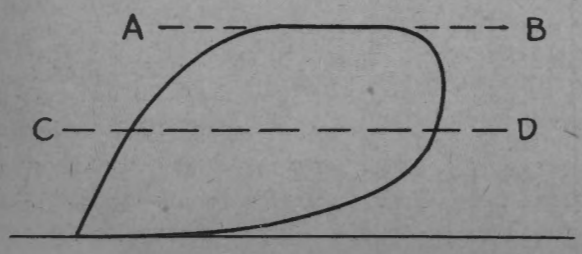


Figure 93—Cosecant squared beam.

5. Attenuation of Transmitted Pulse.

The energy that is available for producing an echo decreases with range because the transmitted pulse spreads as it travels away from the radar. If the pulse is traveling toward a target at high altitude, the energy in a unit area decreases as the square of the range. The small fraction of the incident energy that is reradiated toward the radar also decreases as the square of the range. The net effect of this two-way attenuation is to cause the amount of energy returned to the radar from a target at high altitudes to vary inversely as the fourth power of the range.

For targets on the surface, however, the attenuation is even greater because of the partial cancellation inherent in low-angle radiation when water reflection takes place. For example, in figure 94, the direct and reflected paths are almost the same length because very small angles are involved. The path RST is always slightly longer than path RT, but with the 180° phase shift that takes place on reflection, partial cancellation reduces the energy to a small value. Only at very close ranges is the difference in path lengths great enough to permit the two fields to add over an appreciable area of the target. As a result, the effect of water reflection is to reduce the size of the echo from a distant surface target by an even greater amount than normal attenuation would indicate. It has been found that the received energy from distant

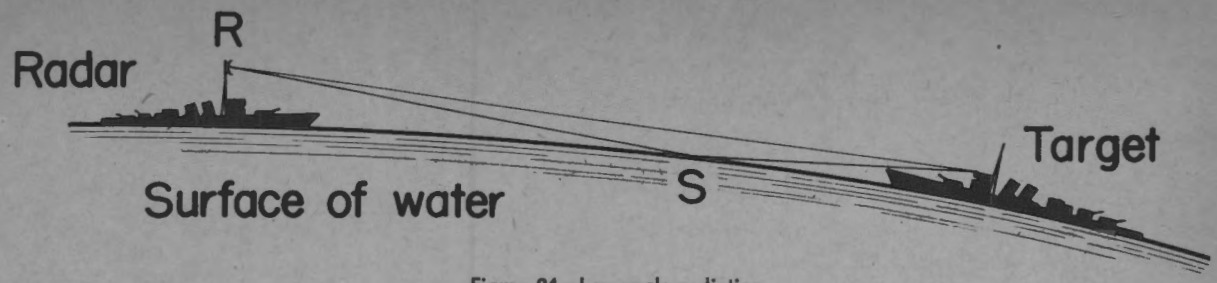


Figure 94—Low-angle radiation.

surface targets varies inversely as the eighth power of the range, approximately. Considerably greater attenuation is experienced beyond the horizon because only a very small part of the pulse is diffracted around the curve of the earth, and that is strongly affected by interference.

The atmosphere itself does not attenuate radiated electromagnetic energy appreciably if the wavelength is longer than approximately 10 centimeters. Therefore, the P and L bands suffer only the normal inverse fourth power attenuation with range. However, in the microwave region, the wavelength is so short that the gases and water vapor that make up the atmosphere begin to absorb energy from the passing electromagnetic waves. The attenuation so caused is in addition to the normal inverse fourth power attenuation caused by the spreading of the energy over a larger and larger area as the range increases. The attenuation caused by absorption is very small for the *S* band, but it becomes increasingly more important as the wavelength decreases. In addition to having relatively high absorption loss in clear weather, *K* band radar suffers a range decrease to approximately 50% of maximum in rainy weather, and there is a noticeable drop in the performance of *X* band sets because of rain. Radars that operate at frequencies in the *S*, *L*, and *P* bands do not encounter any increased absorption in rainy weather—probably because the wavelength is large compared with the size of the raindrops.

6. Effect of Type of Target.

Radio frequency energy is reflected to some extent at any surface that presents a discontinuity. Reflection takes place best from a plane surface at right angles to the radar beam. Since a metal surface presents a very great discontinuity, it sends back a strong echo. Although the best echoes are obtained from conducting objects, non-conducting targets will also return an echo. Thus, echoes are sometimes received from wooden boats, birds, fish, and clouds, especially with microwave radar. Probably a low-lying wooden boat can be detected farther optically than by radar.

The amount of energy reflected back to the radar is nearly proportional to the effective area of the target as long as the target is large compared to the wavelength of the transmitted energy. Very small targets, such as submarine periscopes and small buoys, can therefore be detected at much greater range with microwave radar than with long wave. Large targets, such as high mountains, can be detected at very long ranges with all types of radar, so that transmitted power and antenna height rather than the frequency of the set are of paramount importance in making landfalls by radar.

A radar target is never a single point. If it is a large object, it is composed of a number of variously oriented surfaces and corners, each of which is responsible for a little of the echo returned from the target. Since the target rarely presents a flat vertical surface, the distances between the radar and the various parts of the target often will be slightly different. As a result of these small differences in range, the signal components returned by the many parts of the target may be out of phase by the time the echo returns to the radar. The strength of the whole echo signal will depend on whether these components partially cancel or reinforce each other. For example, with a radar operating on the X band the path lengths to and from various parts of a target need differ by less than a half inch to cause variation in the composite echo. As either the radar or the target changes orientation, the echo power may vary by a factor of as much as 100.

Since airplanes change aspect more rapidly than other types of targets, airplane echoes fluctuate more widely and more rapidly than those from other types of targets. It has been found that the reradiation pattern of an airplane is composed of many irregular narrow lobes, so that a very slight change of target angle may cause a very large increase or decrease in the echo height. In general, the echo from a plane is greater when the target angle is approximately 045°, 135°, 225°, or 315°, than at other angles. The rapid, irregular fluctuation in the size of the echoes returned to microwave radar by airplanes has been termed "glinting." This effect is not noticeable at low radar frequencies or on slow-moving targets because the pattern of cancellation and reinforcement of the echoes cannot vary rapidly.

The echoes from surface vessels fluctuate con-

siderably less than those from aircraft because, in large ships at least, a large part of the target area is the relatively flat side of the hull. When ships are hull down, or when they are small and rolling in the seas, the fluctuations are rapid and of relatively great amplitude. The target angle of surface targets has little effect on the fading of echoes at ranges beyond approximately 5,000 yards.

Land echoes are much steadier than those from either surface vessels or aircraft. However, even these echoes are often not perfectly steady because of movement of foliage in the wind. In general, a single isolated target on land, such as a standpipe or lighthouse should produce a very solid echo.

The amount of fluctuation of echoes from all types of targets is affected by the state of the surface of the sea. In a dead calm when there are no waves or swells, the fading is least. As the surface becomes more ruffled, the echoes fluctuate more because of the variation in the amount of energy that reaches the target by way of the path involving reflection off the water.

Another factor that contributes to the fluctuation of echoes of a microwave radar is the large number of closely spaced lobes and nulls through which the target must move (see fig. 90B). This factor is of minor importance for long-wave radars because of the great extent and relatively small numbers of the lobes in the antenna pattern.

In many cases the atmosphere through which the radar pulse travels is not perfectly uniform. The radar waves are, therefore, not bent away from a straight path by the same amount at every point along their travel, nor is the amount of bending constant with time. Fluctuations caused by irregularities in the atmosphere are not apparent in calm air, but they become quite noticeable when the air is turbulent. The variation in the refraction of radio waves that is caused by turbulence in the air results in varying distribution of energy over the front of the moving pulse, and consequently in fluctuations of echo height.

The effect of fading of the echoes is minimized in some fire control radars by the use of automatic gain control (*AGC*). This type of circuit allows echoes from any selected single target to control the gain of the receiver. If the echo fades, the gain of the receiver is automatically increased so that the selected pip height is unchanged, but all the other echoes vary.

A special case of reflection takes place when radiation is directed at an object composed of two plane reflecting surfaces which are at right angles. Such a reflector is called a corner reflector. The property of a corner reflector which makes it of value is that any ray which can enter the corner is reflected out of the corner along a path parallel to the incoming ray. The geometry of the corner reflector is shown in figure 95 to illustrate this effect. A ray *AB* which enters the corner at any angle θ with the vertical side will be reflected from this surface at the same angle θ. Therefore, the angle at which the reflected ray strikes the horizontal side is 90-θ, and the ray leaves the corner along *CD*. If this ray is projected back to *B*, it is clear that *AB* and *DCB* intersect the vertical plane at the same angle, so that these rays must always be parallel.

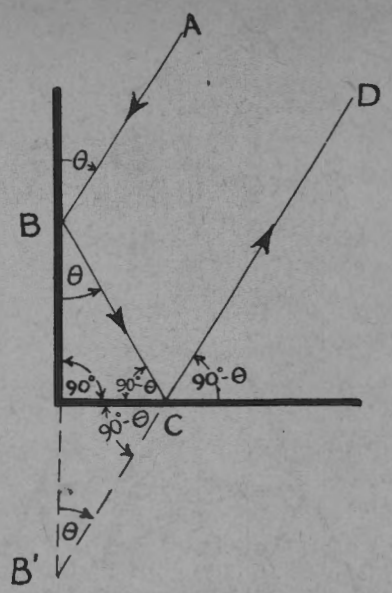


Figure 95—Corner reflector.

A reflector of this sort will produce a very strong echo on a radar because the energy that strikes the corner is reflected back directly to the radar without the excessive scattering that occurs with most targets. Metal corner reflectors are used often as artificial targets. However, such reflectors can frequently occur in nature, as in rock formations, sharp vertical cliffs that rise out of the water, or in the many perpendicular metal surfaces aboard ship. Artificial corner reflectors are usually made in the form of three sides of a cube rather than simply as two perpendicular planes. The larger the corner reflector is made, the greater will be the energy intercepted, which will produce a stronger echo.

Since corner reflectors return strong echoes for their relatively small size, they have found use in many applications. For example, they are used on aerological balloons that are tracked by radar, on special radar buoys, as artificial targets for use in boresighting radars, in target sleeves, on target rafts (fig. 96), and on life rafts. Targets which are rounded, as opposed to a corner reflector, so that no surfaces are perpendicular to each other probably will be hard to detect by radar.

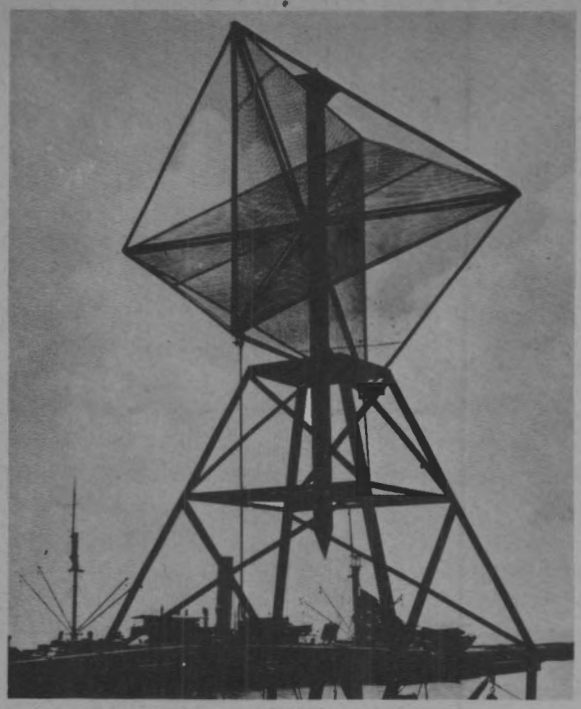


Figure 96—Corner reflector for target raft.

B. NON-STANDARD PROPAGATION OF RADIO WAVES—TRAPPING

1. General Features.

When the atmosphere is well mixed so that no unusual temperature or humidity gradients are likely to exist, standard propagation conditions should prevail. Considerable mixing of the atmosphere occurs with high, gusty winds, or in a region of low barometric pressure which is usually accompanied by turbulence. Standard propagation is likely also when the water is colder than the air, or over land when cooling of the earth by radiation is limited by overcast skies. If rain is falling, the lower atmosphere in general will be saturated with water vapor, so that the existence of abnormal humidity gradients is prevented and propagation should be standard.

In the standard atmosphere both the air temperature and the moisture content decrease uniformly with height above the surface of the earth, so that the index of refraction of the atmosphere also decreases uniformly. However, the atmosphere is subject to many changes. The temperature may, for example, first increase with height and then begin to decrease. Such a situation is called a *temperature inversion.* More important, the moisture content may decrease markedly with height just above the sea. This latter effect, which is called a *moisture lapse,* either alone or in combination with a temperature inversion may produce a great change in the index of refraction of the lowest few hundred feet of the atmosphere. The altered characteristics of the atmosphere may result in an excessive bending of the radar waves that are passing through the lower atmosphere. In certain regions, notably in warm climates, excessive bending is observed as high as 5000 feet. The amount of bending in regions above this height is almost always that of normal atmosphere.

The atmosphere must be relatively calm in order to permit the existence of the conditions that produce this excessive bending. After a period of calm or of light breezes, the lower air may be stratified so that non-standard propagation is likely throughout a wide area. There will be formed within this area a sort of duct or waveguide in which the radar waves can be trapped. The most remarkable effect of such trapping is the extreme ranges that have been obtained as a result of it. Ships using 200-megacycle search equipment have detected land at ranges between 300 and 400 miles, and rather small ships have been detected at ranges up to 50 miles.

The duct in the atmosphere may be formed along the surface of the sea or elevated above the earth. In either case, the coverage of the radar will be changed by the great extension of detection range for targets within the duct. In figure 97, one possible type of deformation of a radar coverage pattern is illustrated. The duct illustrated acts very much like the waveguide that is used as the transmission line in surface search radar. The humidity gradient is such that the rays from the radar antenna are bent an excessive amount,

A. Radar lobe pattern in standard atmosphere. . . . Steady variation of temperature and humidity aloft.

B. Radar lobe pattern in nonstandard atmosphere. . . . A duct has been formed on the surface and ship is detected.

Figure 97—A possible effect of trapping.

and they are trapped in a zone near the surface of the water. Since the effect of the duct indicated in figure 97 is to guide the radiated energy around the curvature of the earth and back again to the antenna, the radar is able to detect the ship at a range much greater than normal.

If the moisture content of the air increases with height, the radar waves may be bent up instead of down. Non-standard propagation of this sort reduces the radar coverage instead of increasing it.

2. Effect on Radar Performance.

The position of the radar antenna relative to the duct in the atmosphere is one of the most important factors in controlling the effect of trapping. The radar pulse can be trapped and carried out to very distant targets and back to the radar if the antenna lies within the duct. If the antenna lies below the duct, trapping may take place, but only if the radiated rays from the antenna enter at a very small angle. For this reason, elevated ducts that are very high will not have any direct effect on radar performance. On the other hand, if the antenna is a small distance above the top of the duct, blind zones may be present in the low-level portion of the coverage pattern that do not exist during standard propagation conditions. However, if the antenna is high above the top of the duct, as an airplane flying over a ground-based duct, no effect on the airborne radar coverage will be apparent.

Since the ducts that are most important to the operation of shipboard radar are ground based, radars that have relatively low antenna heights are the most likely sets to experience trapping. Experiments and observations of shore radar installations in both the United States and England have indicated that low sites are rather generally affected by trapping while high sites experience the phenomenon relatively infrequently.

For some time after the discovery of trapping it was thought that the long ranges observed resulted from the diversion of a large amount of the radiated energy into the duct. Consequently, it was feared that the existence of trapping would cause a great decrease in coverage in the area above the duct. However, the conditions that exist in the most common type of trapping do not support this presumption. In spite of the great increase in ranges in the duct, the amount of energy trapped is small compared to the total energy radiated in the pulse. The increased range apparently is caused by the increased transmission efficiency that exists within the duct.

In many cases, coverage will be reduced for targets that are *just* above the duct. This reduction is caused by the waveguide action of the trapping layer. The radiated pulse is contained within the duct because the refractive power of the atmosphere within this region is such that the radiated rays are bent downward. Directly above the duct there may then be little or no energy, and targets flying there may not be detected. However, energy may reach targets that are well above the duct by travelling along paths that enter the trapping region at angles too great to be trapped.

The wavelength that can be trapped in the duct formed by non-standard propagation conditions varies with the height of the duct. If the duct is approximately 400 feet high, all radar frequencies can be trapped within it. However, if the duct is only 100 feet high, only microwave energy will be affected. A duct almost always exists within perhaps the first 20 feet above the water, but this is not yet of any practical use since only K band energy could be trapped within such a narrow region. There is fairly conclusive evidence of the rather general existence of a surface duct 50 to 65 feet high throughout the trade wind area of the Pacific ocean. This duct is capable of trapping S band and shorter wavelengths provided the antenna lies within the duct. Because of the characteristics of the ducts that are usually formed, radar frequencies

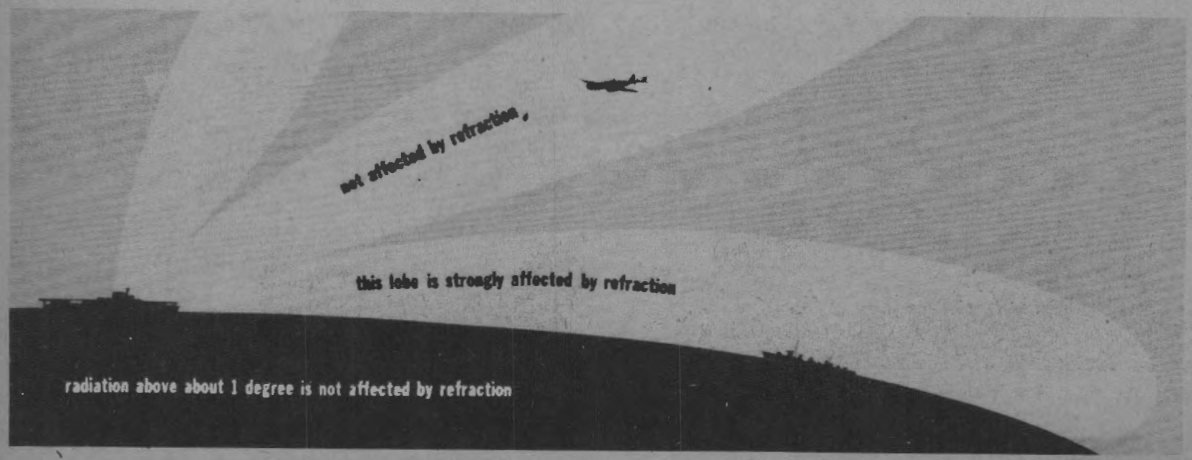

not affected by refraction
this lobe is strongly affected by refraction
radiation above about 1 degree is not affected by refraction

Figure 98—Regions in which refraction affects antenna patterns.

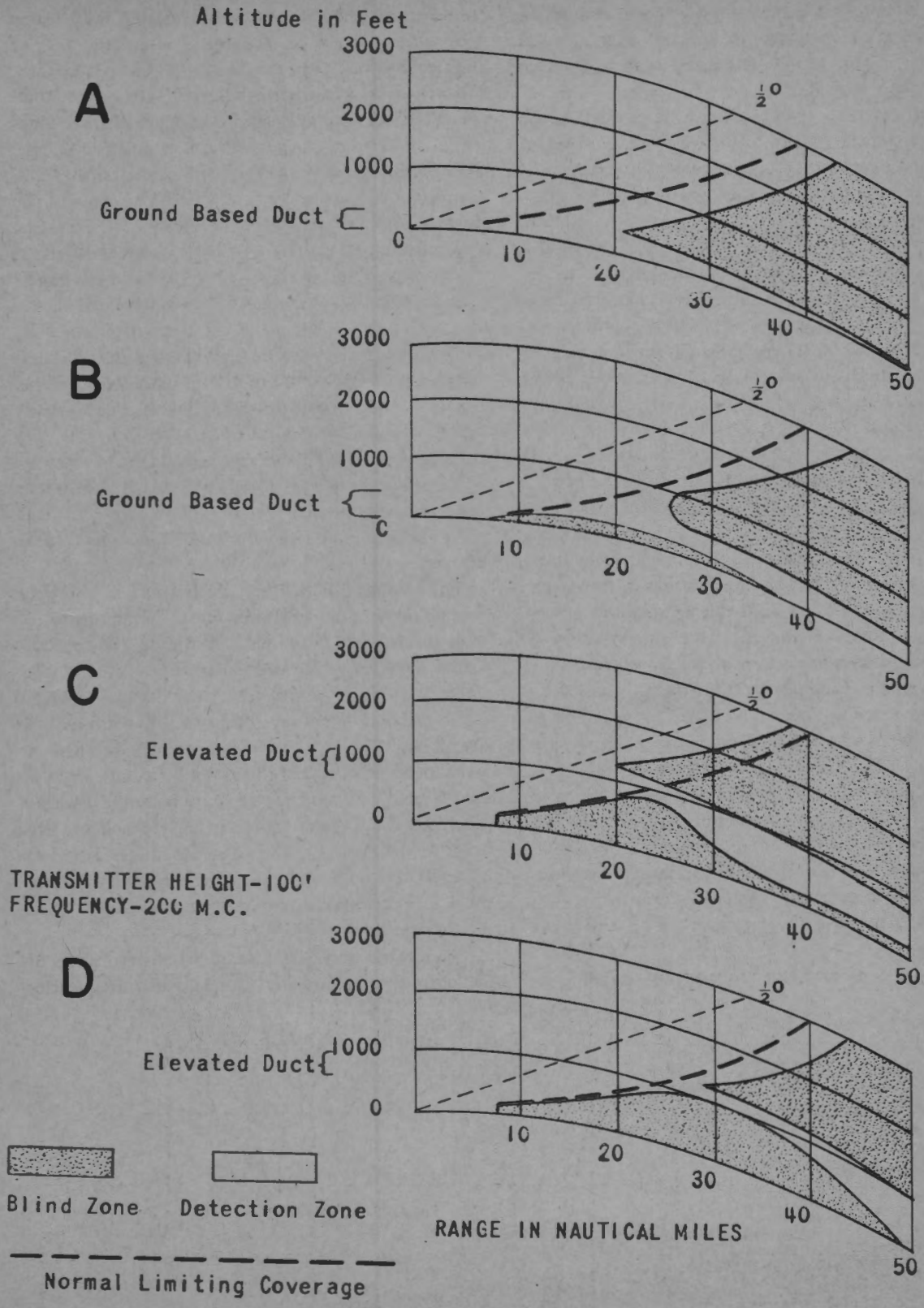


Figure 99—Coverage diagram showing deformation of lowest lobe.

below approximately 250 megacycles are the least likely to be trapped.

The amount of refraction, that is the amount of angular deflection of the rays, is very small and very rarely will exceed one degree. Such bending does not affect radar operation except in regions where the angle between the radiated ray and the horizontal is very small. When radar is used for AA fire control, the targets are usually at medium or short ranges, and the angle between the line of sight and the horizontal is usually larger than one or two degrees. Trapping has practically no effect on such applications of radar.

With air search radar the target may be an airplane fifty or a hundred miles away flying at an elevation of only a few thousand feet. In this case, the position angle of the target is only a fraction of a degree and for surface targets the position angle is even smaller. Only low-angle search is affected by meteorological conditions; performance of the radar is rarely affected by weather for targets above approximately 1° position angle (figure 98).

A coverage diagram for standard conditions is shown in figure 90A with height greatly exaggerated. Only the lowest three lobes are shown and the higher lobes appear compressed as compared with the lowest lobe. In figure 99 the lower part of the same diagram is drawn as it appears under a few conditions of trapping. The bottom part of the normal lowest lobe is shown by a broken line. The lines which separate the "blind zones" from the "detection zones" represent the range at which a medium bomber would just become visible to this particular radar set.

The diagrams clearly indicate the great extension of ranges in the duct, and also the moderate change in ranges—sometimes an extension, sometimes a reduction—above the duct. Another feature of some of these diagrams is the appearance of "skip ranges." A plane flying at an altitude of 500 feet, for example, would be detected early under the conditions shown in *C* and *D*. As the plane approaches, the echo will disappear from the indicator and reappear only at a range less than 20 miles. Similar conditions may exist for sea return. In *B* there may be echoes from waves close in and also from beyond 33 miles, but not in the space in between. For conditions shown in *D*, there will be echoes from very remote surface targets or land, but not from targets at intermediate ranges.

The lobe structure of an air search radar is not affected by trapping even though a duct high enough to trap P-band energy may be found in the atmosphere, since only the lowest lobe is deformed. Thus, trapping has no effect on the accuracy of altitude estimation by the use of fade charts. However, if altitude is estimated from the range that a plane is first detected, the estimate may be seriously in error. If the plane is flying in the duct, the estimated altitude is likely to be too high because the echo appears sooner than it would under standard conditions. On the other hand, if the target is flying just above the duct, the echo will be detected at a shorter range than normal, and the estimated altitude will be too low. The accuracy of measurement of altitude by radars that use lobe switching or a fanning beam should not be affected by trapping conditions, because when targets are at a position angle at which accurate

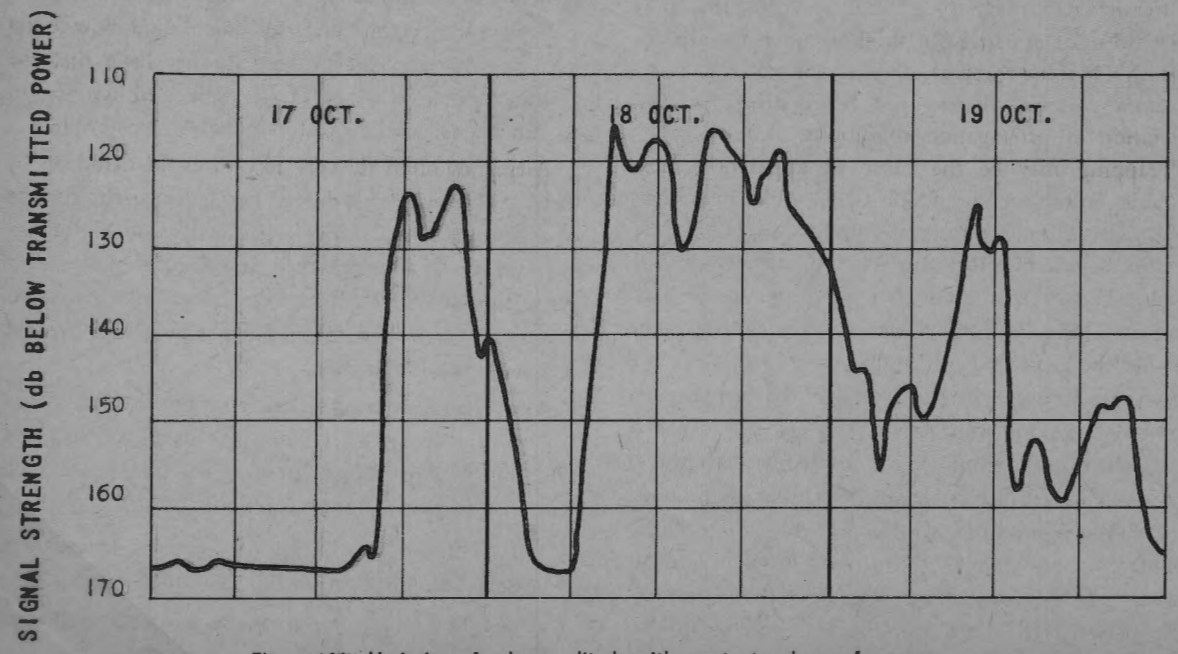


Figure 100—Variation of echo amplitude with constant radar performance.

measurement is possible, the radar waves make too great an angle with the horizontal for them to be trapped.

A very serious operational consequence of trapping is the misleading of radar operators as to the overall performance of the equipment. Long-range echoes caused by trapping have frequently been assumed to indicate good condition of the equipment when precisely the opposite may be the case. For example, figure 100 shows a part of a record of echo amplitude taken during an investigation of radar propagation. The performance of the radar was maintained at a constant level by the use of an echo box. The target was 30 miles away from the radar, with the path of the pulses passing over sea. Aside from the rise and fall of the tide, the variations in echo strength are due to changing characteristics of the targets or of the propagation pathway. The tremendous variation shown in figure 100 would certainly preclude the use of this target as a standard to check the performance level of a radar. At one point in the curve, the echo changed 200,000 fold (53db) within 2½ hours. However, the phenomenon of trapping does not invalidate the measurement of echo height on *nearby* targets as a criterion of over-all set performance, since the echoes from objects well within the optical horizon are not affected appreciably by propagation variations.

Under conditions where the security of radar transmissions is involved, the possibility of trapping should be constantly kept in mind. When a duct is present, the enemy can intercept both radar pulses and VHF communications at far greater ranges than normal. When trapping is known to be present, and a choice of frequencies is available, it may be better to choose the lowest band since the high frequencies are the more likely to be trapped. Thus, decisions as to when to employ radar silence must be modified by consideration of propagation conditions.

Trapping may be the cause of apparently inexplicable failure in communications. Elevated ducts do not have much effect on ship-to-ship or ground-to-ship communications unless the duct is at 'ow level. However, a plane flying within an elevated duct may have difficulty communicating with a plane outside the duct or with a distant ship because the duct may act as a barrier. When the temperature inversion and moisture lapse are very steep over a relatively thin layer of the atmosphere, radio waves may be reflected directly from the bottom of the duct. Under this condition, which probably will be encountered only rarely, the lower frequency radar and communications waves may be reflected repeatedly between the duct and the sea, and so carried long distances, even without trapping taking place. There will be skip distances associated with this type of propagation because the nature of the reflection is such that the waves are returned to earth only at intervals. If a plane is flying above a thin, sharply bounded duct of this type, it may be impossible for communications to be established between the plane and the ship. In rare cases a phenomenon of this sort may also be responsible for failure of IFF. When communications from a plane fail, or the plane cannot make contact on a navigational aid, the pilot may be able to reestablish contact by changing altitude to get either above or below the duct.

When trapping causes echoes to be returned from targets at long ranges, the pips are likely to fluctuate far more than those from targets at short range. This fading is caused by changing propagation conditions within the duct. Such fading is of large amplitude, perhaps involving a change in echo power of as much as 1000 fold, and the echoes vary over a period of approximately 15 minutes. Violent fading of echoes appears to be a characteristic feature of trapping conditions that may aid the operator in realizing when such conditions exist.

If the water vapor content of the air increases with elevation, the radar waves are bent up instead of down. This condition, which is referred to as substandard, can exist in some kinds of fog or when fog is about to form. Although not enough is yet known about radar propagation in fogs to state its full effect, it appears likely that nearly all fogs produce substandard conditions. The obvious danger of this condition is that the fog prevents ordinary optical search, and at the same time reduces the radar detection range on surface vessels and low-flying aircraft. Unfortunately, there is very little that the operator can do to combat the effect of fog except to run his set at the greatest possible sensitivity.

Airplanes often fly very low to avoid detection by radar. However, if a duct is formed near the surface of the water, such evasive action will probably be unsuccessful. If the presence and height of the duct were known, better protection against radar detection would be furnished if the planes were to fly just above the top of the duct.

The changing propagation conditions that radar waves can encounter, then, can have considerable effect on radar performance. To summarize, the effect of trapping on a radar may be to:

(*a*) Increase the range of detection for surface vessels and airplanes flying within a duct.

(*b*) Reduce the range of detection for airplanes flying just above a duct.

(*c*) Reduce the range of detection for surface vessels and low-flying planes in some types of foggy weather.

(*d*) Modify the height at which airplanes should fly to avoid detection by enemy radar.

(*e*) Cause errors in height finding for targets below position angles of 1°.

(*f*) Increase the extent of clutter from sea return, and thus reduce the operational efficiency.

(*g*) Increase the range to which a navigational aid can be effective.

(*h*) Increase the range at which radar signals can be heard.

(*i*) Modify the degree of jamming either suffered or inflicted.

Weather effects cannot be blamed indiscriminately for variable performance of radar. In general, inadequate adjustment or incipient electrical failure will cause a far greater decrease in range than any variation in the propagation conditions. For example, failure to detect a high-flying airplane at short range cannot be attributed to non-standard propagation; trapping affects the detection of targets only at low angles above the horizon.

3. Meteorological Factors That Cause Trapping.

The atmospheric conditions which allow standard propagation to take place are common. The peculiar structure of the atmosphere that produces trapping, especially for frequencies of 3,000 megacycles and higher, also occurs fairly often in many parts of the world. Several types of meteorological conditions can produce the temperature and humidity gradients necessary for trapping to take place.

Warm continental air blowing over a cooler sea leads to the formation of a duct by causing a temperature inversion as well as by evaporation of water from the cooler sea into the lower levels of the warm dry air. The base of such a duct is usually the sea surface with the trapping region extending several hundred feet upward. At higher latitudes—above 25° or 30°—this type of trapping is most prevalent along the eastern shores of continents. If it is present in the lower latitudes, the duct will be formed on the western coasts. This distribution with latitude results from the normal direction of the wind, which must be off-shore to produce the effect. Ducts of this sort will form only when there is a distinct temperature difference between the sea and the air blowing from the land. Hence, conditions are most favorable for trapping in the summer months. The duct is usually from 500 to 600 feet high, and it tends to remain level for a distance of 100 to 200 miles out to sea. Near the coast trapping will be found to be strongest just after noon, and weakest just before dawn. Fog usually is not associated with the meteorological conditions that produce this form of trapping, but at times a surface fog will be observed 5 to 10 miles off shore.

Over the open ocean, a surface duct may be formed by cool air blowing over a warmer sea. There is no temperature inversion associated with this phenomenon, and the entire effect is caused, apparently, by the evaporation of water into the lower levels of the atmosphere. Ducts of this sort are often created by easterly winds, such as the trade winds, that have blown for a long distance over the open sea. The height of the duct increases with the wind speed, and at the higher wind speeds typical of the Pacific trade belt—10 to 20 knots—ducts 50 to 60 feet high occur quite generally. These ducts seldom attain the height and intensity necessary to entrap the lower frequencies, but *S* and *X* band radars that have antennas within the duct show better range performance for the detection of surface vessels and low-flying aircraft than can be predicted from consideration of the characteristics of the radar alone. These ducts are important because they extend for long distances.

An elevated duct may form in an area of high barometric pressure because of the sinking and lateral spreading of the air, which is termed subsidence. When the air is warm and dry and the subsidence takes place over the sea, water is evaporated into the air, forming a moisture gradient that leads to the formation of a duct. Such ducts are always formed above the sea, with the base of the trapping layer ranging in elevation from a few thousand to 20,000 feet. Subsidence trapping can nearly always be found in the tropics; the ducts so produced usually are low and strong off the western coasts of continents in the trade winds latitudes, and high and weak near the equator. In areas where a monsoonal climate is found, subsidence trapping is weak or nonexistent in the moist, onshore, summer monsoon, and the duct is low and trapping strong during the dry, offshore, winter monsoon. When a duct is formed as the result of subsidence, the strength of the trapping varies throughout the day, being weak in the mid-forenoon, and strong after sunset.

Other meteorological conditions that may produce trapping are cooling of land at night by radiation and the mixing of two masses of air, as at a warm or cold front. The ducts formed by these effects are likely to be of such limited extent that they are unable to modify radar propagation by any appreciable amount.

4. Prediction of Nonstandard Propagation.

In spite of the fact that the relation of weather to the production of trapping conditions is not fully

understood, enough is known to permit a meteorologist to make a fairly reliable prediction. Considerable equipment is required to measure the several variables that must be known to determine the structure of the atmosphere, and rather specialized meteorological skills are needed to interpret the data. Since neither the skills nor the equipment is generally available to the fleet, reliable predictions are difficult to make on board ship. However, even in the absence of specialized equipment and personnel, it may sometimes be possible to predict the formation of ducts from observation of weather conditions, coupled with simple measurements that can be made on board any ship. Such an estimate cannot hope to be highly reliable at present, but continuing research on the problem may ultimately reveal a fairly simple relationship between weather and trapping that will allow propagation conditions to be evaluated routinely.

For a number of reasons the meteorological conditions in a region of high barometric pressure are favorable for the formation of ducts. Among the favorable factors are: subsidence, which creates temperature inversions, and which occurs in areas where the air is very dry so that evaporation can take place from the surface of the sea; calm conditions that prevent mixing of the lower layers of the atmosphere by turbulence, allowing thermal stratification to persist; and clear skies which permit nocturnal cooling over land.

The conditions in a barometric low, on the other hand, generally favor standard propagation. A lifting of the air, the opposite of subsidence, usually occurs in such regions and it is accompanied by strong winds. The combined effect of these factors is to destroy any local stratification of the atmosphere by a thorough mixing of the air. Moreover, the sky is usually overcast in a low pressure area, and nocturnal cooling is therefore negligible. Very often rain falls in a low pressure area, and the falling drops of water have the effect of destroying any non-standard humidity or temperature gradients that may have been established.

In all of the weather conditions that produce trapping, the atmosphere must be sufficiently stable to allow the necessary stratification of the atmosphere to be established and to persist. Thus, continued calm weather or moderate breezes are necessary. It must be emphasized, however, that even if weather conditions may favor the formation of ducts, they do not always produce them.

In terms of the readily observable phenomena, the weather conditions that may favor trapping are:

(*a*) A moderate breeze that is warmer than the water, blowing from a continental land mass.

(*b*) Clear skies, little wind, and high barometric pressure.

(*c*) A cool breeze blowing over the open ocean far from large land masses, especially in the tropical trade wind belt.

(*d*) Smoke, haze, or dust fails to rise, but spreads out horizontally, which indicates quiet air in which a temperature inversion may exist.

(*e*) The air temperature at bridge level on the ship definitely exceeds that of the sea, or when the moisture content of the air at bridge level is considerably less than that just above the water, and the air is relatively calm.

Although trapping conditions can occur at any place in the world, the climate and weather in some areas make their occurrence more likely. In some parts of the world, particularly those possessing a monsoonal type of climate, variation in the degree of trapping is mainly seasonal, and enormous fluctuations from day to day may not occur. In other parts of the world, especially those in which low barometric pressure areas recur often, the extent of non-standard, propagation conditions varies considerably from day to day, even during the season of greatest prevalence.

Even though the geographical and seasonal aspects of trapping are not yet so firmly established that a map of the world can be drawn with trapping areas reliably delineated, it is possible to make a general summary.

(*a*) *Atlantic Coast of the United States.*—Along the northern part of this coast, trapping is common in summer, while in the Florida region the seasonal trend is the reverse, with a maximum in the winter season.

(*b*) *Western Europe.*—On the eastern side of the Atlantic, around the British Isles and in the North Sea, there is a pronounced maximum of trapping conditions in the summer months.

(*c*) *Mediterranean Region.*—Available reports indicate that the seasonal variation is very marked, with trapping more or less the rule in summer, while conditions are approximately standard in winter. Trapping in the central Mediterranean area is caused by flow of warm dry air from the south (Sirocco) which moves across the sea and thus provides an excellent opportunity for the formation of ducts. In the winter time, however, the climate in the central Mediterranean is more or less a reflection of Atlantic conditions and hence it is not favorable for duct formation.

(*d*) *The Arabian Sea.*—The dominating meteorological factor in this region is the Southwest Monsoon that blows from early June to mid-September and covers the whole Arabian Sea with

moist equatorial air up to considerable heights. When this meteorological situation is fully developed, no occurrence of trapping is to be expected. During the dry season, on the other hand, conditions are very different. Trapping is then the rule rather than the exception, and on some occasions extremely long ranges, up to 1,500 miles, have been observed on *P*-band radar on fixed echoes.

When the Southwest Monsoon sets in early in June, trapping disappears on the Indian side of the Arabian Sea. However, along the western coasts conditions favoring trapping may still linger. The Strait of Hormuz is particularly interesting as the monsoon there has to contend against the Shamal from the north. The Strait itself lies at the boundary between the two wind systems, and a front is formed with the warm, dry Shamal on top and the colder, humid monsoon underneath. As a consequence, conditions are favorable to the formation of an extensive duct which is of great importance to radar operation in the Strait of Hormuz.

(*e*) *The Bay of Bengal.*—The seasonal trend of trapping conditions is the same as in the Arabian Sea, with standard conditions occurring during the summer Southwest Monsoon, while trapping is found during the dry season.

(*f*) *The Pacific Ocean.*—This region appears to be one where, up to the present, least precise knowledge is available. However, there seems to be definite evidence of the frequent occurrence of trapping around Guadalcanal, the east coast of Australia, and around New Guinea. Observations along the Pacific coast of the United States indicate frequent occurrence of trapping, but no clear indication of its seasonal trend is available. The meteorological conditions in the Yellow Sea and the Sea of Japan, including the island of Honshu, are approximately like those off the northeastern coast of the United States. Therefore, trapping in this area should be common in the summer. Conditions in the South China Sea approximate those off the southeastern coast of the United States only during the winter months, when trapping can be expected. During the rest of the year, the Asiatic monsoon modifies the climate in this area and no data are available as to the prevalence of trapping during this time. The trade winds in the Pacific lead to the formation of rather low ducts quite generally over the open ocean.

C. WEATHER

1. Roll and Pitch of Ship.

The state of the weather had relatively little effect on the early, low-frequency radars, but as development continues and the fleet is supplied with microwave equipment that operates on very short wavelengths, the weather may have a profound effect on radar operation. However, one factor that affects all radars is the roll and pitch of the ship in which the radar is installed. The energy transmitted from a radar antenna is confined to a beam by the directivity of the antenna. If the vertical width of this beam is narrow, then rolling of the ship may cause the radar to miss some targets at some times, as indicated in figure 101. In small ships the amount of roll is often great enough to prevent reliable use of radar. As a result, some of the more recent surface search equipments for small vessels, such as model SU radar, have antennas that are stabilized. Some of the new surface search radars for large vessels also have stabilized antennas in order to take advantage of the concentration of energy into a narrow beam that is possible when the beam is forced to scan the horizon irrespective of the movement of the ship. Stabilization of the antenna is necessary in radars that are used to determine altitude of airborne targets by measuring position angle. In the case of air search radars, however, the vertical beam width is usually no narrower than 20° so that the roll of the ship usually is insufficient to pull the beam off target.

2. Sea Return.

Since some of the energy radiated by a radar strikes the surface of the sea, echoes are returned from the water when the surface is disturbed by waves.

Radar echoes from waves are called sea return. Those echoes show on a PPI screen as an irregular bright area around the center of the screen. The range to which sea return extends on the indicator

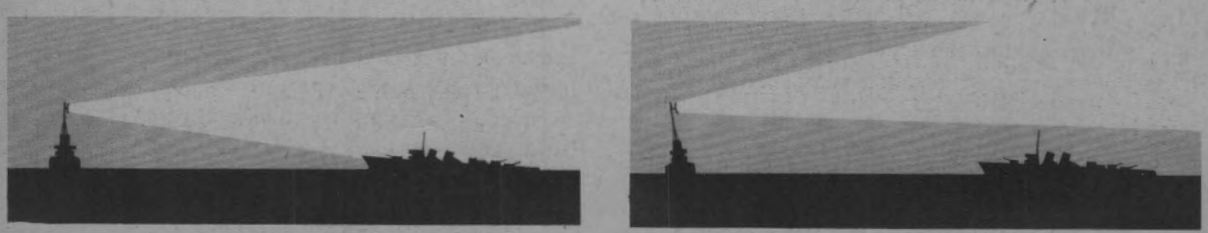


Figure 101—Effect of roll of ship on antenna coverage.

depends on the roughness of the ocean, the height of the antenna, and the peak power of the radar. In very calm water, sea return is of negligible importance. However, in very rough weather, it will be impossible to see targets within several miles of the radar because all echoes are lost in the clutter from sea return. Increasing the height of the antenna or the power radiated also causes an extension of the sea return.

Sea return is usually stronger upwind than downwind because the fronts of the waves are more nearly vertical, and therefore better reflectors, than the sloping backs. In addition, somewhat stronger echoes are obtained in a direction perpendicular to the waves than along the troughs. Consequently, it is frequently possible to estimate the direction of the surface wind from the oval shape of the sea return on a PPI screen.

The effect of sea return on the indicator can be considerably reduced by lowering the gain of the radar receiver. However, such an adjustment prevents the radar from detecting objects at a distance.

Station keeping by radar is made difficult by sea return, since the clutter on the screen often masks the echoes from nearby ships. A recent improvement in the design of radar receivers should almost completely prevent this effect. The addition of Sensitivity-Time Control (STC), Instantaneous Automatic Volume Control (IAVC), and Fast Time Constant (FTC) enable the radar to discriminate against echo signals, such as sea return, which extend over a long range in favor of the strong isolated signals returned from nearby ships.

Sensitivity-Time Control reduces the gain of the radar receiver for the first few miles of the sweep, and then restores full sensitivity for the remainder of the sweep. Thus the gain is low in the region from which the echoes are returned from waves, reducing the extent of sea return, yet full sensitivity is available to enable an effective long range search to be conducted.

Sea return echoes are reflected from a general area, so that in general these echoes cover a longer range than normal pips. The Instantaneous Automatic Volume Control circuit reduces the receiver gain for these longer echoes, but it maintains receiver sensitivity for the relatively short normal echoes. As a result, IAVC prevents sea return from forming a solid pattern around the center of a PPI scope, but it does not eliminate the clutter completely. (See fig. 136).

The Fast Time Constant video coupling circuit in the receiver also acts to prevent the passage of long echo pulses. It is designed to pass a normal echo with slight change, but it removes part of the long echoes so that they cannot build up a solid pattern on the PPI.

Of these three improvements, Sensitivity-Time Control is designed especially to reduce the effect of sea return, but the other circuits are helpful in the same purpose. However, both Instantaneous Automatic Volume Control and Fast Time Constant coupling are also of use against certain types of jamming and they tend to improve the range resolution of the radar. These circuits are currently being installed in SG radars as part of the modernization program (Field Change No. 50), and they are provided in most radars of recent design.

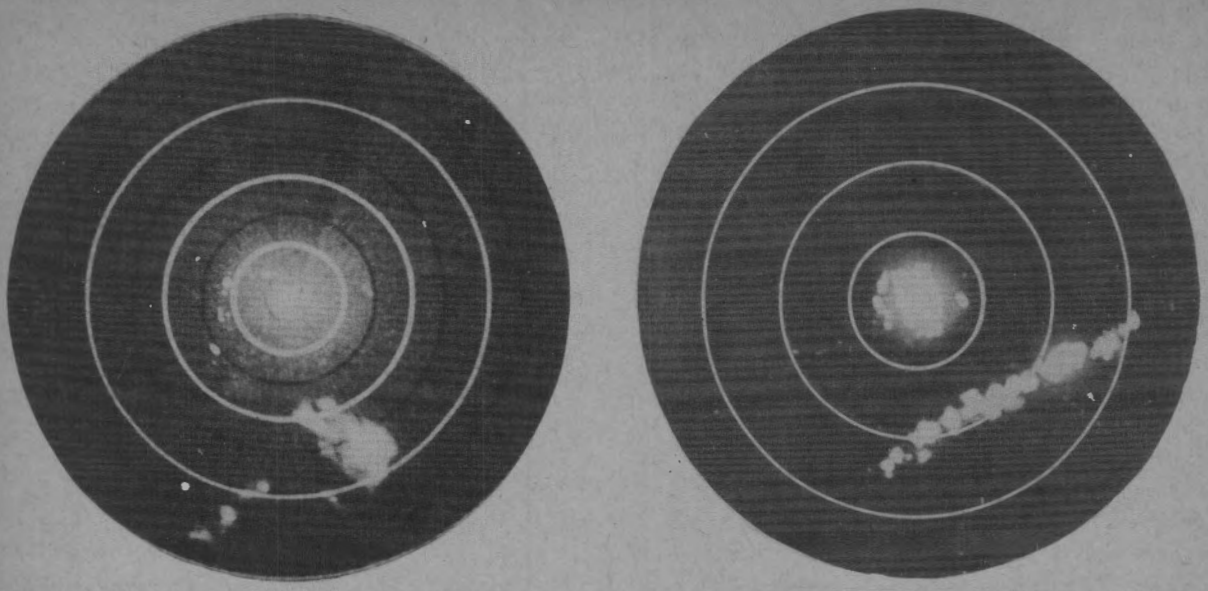
3. Formation of Ice on Antenna.

The effect of ice on radar antennas has been investigated only a little. Other than the mechanical load that it puts on the antenna training mechanism, there is apparently no difficulty presented by formation of ice on open antennas, such as the SC or SK arrays. Microwave radars in which energy is sent into the reflector through a plastic window, as in the SG and SJ, may be practically inoperative if ice forms across the whole area of the window, particularly if the ice is wet. It is unlikely that any ice can form directly on antennas that are covered by radomes —as the SF, SL, SO and SU—but a coating of ice on the radome may reduce radar performance appreciably. The reduction in performance caused by ice is more serious the higher the radar frequency. Perfectly dry, hard-frozen ice seems to have little effect on system performance as long as the thickness of the coating is small compared to a wavelength, but a coating of water on the ice seems to cause a large reduction in range. This reduction appears to be caused equally well by either fresh or salt water.

4. Storms.

As microwave radars have come into general use in recent years the cloud or storm echoes that are frequently seen on the indicators have attracted attention. The possibility of using microwave radar as an aid to meteorological forecasting was recognized early, and it is now being put to operational use.

Knowledge of the mechanism of reflection of radar pulses from storm clouds is still incomplete, but it is generally believed that the reflection is due to scattering by water droplets. The amount of scattering increases very rapidly with frequency, so that storm echoes are most frequently observed on S and X band radars. Cloud echoes are comparatively rare at frequencies below about 1,000 megacycles. Experience seems to indicate that clouds do not produce visible echoes unless the water drops within the cloud



A. Air mass or convection thunderstorm.

B. Thundershowers along a cold front.

Figure 102—Thunderstorm echoes on PPI.

are large enough to yield precipitation. This does not necessarily mean that there is rain at the ground at the place where storm echoes are observed because the drops may evaporate before they reach the ground, or rising currents of air may keep the drops afloat against gravity, a phenomenon very common in cumulus clouds and thunderheads.

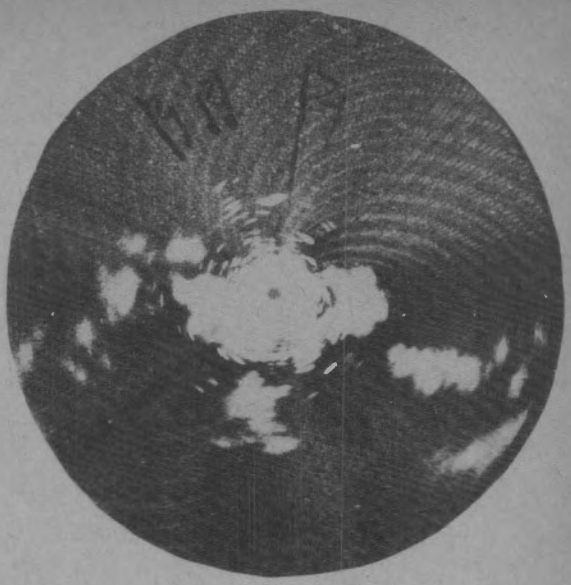
Consequently, not all clouds can be seen on a radar scope. Stratus clouds give very little echo or perhaps none at all, and a general overcast is often invisible to the radar operator. Thunderstorms and frontal squalls usually produce intense illumination on the scope. Thundershowers are of two general types. The isolated air mass or convection type of storm produces a bright, dense echo surrounded by haze, as the echoes shown in the southern sector of figure 102A. The other type of thundershower occurs along a cold front, and may form a line squall. The echo from such a storm may show as a bright line if the storm is fully developed, or it may show as a group of bright spots caused by echoes from individual showers along the front, as in figure 102B.

Unless operators are trained to recognize these types of echoes, they may be interpreted as valid targets. However, if as a result of proper training such echoes are readily evaluated, it will be possible to vector aircraft around the storm areas and to maneuver carriers into clear areas where planes may be easily launched or landed.

Usually storm echoes are not so strong that they blank out the much sharper contours of a plane echo. If the echo from the storm should be so intense as to make the plane echo invisible, the air in this area would be so rough that it is improbable that a plane would intentionally fly in this part of the atmosphere. Therefore, it is unlikely that enemy planes will seek cover in such storms. Since radar can detect objects on each side of the storm area, little protection from radar detection is afforded airplanes by violent localized storms. Cloud echoes usually can be recognized by the operator by their fuzzy, hairy appearance on a type A indicator and by their nebulous, cloudy appearance on a PPI. If the pip is too sharply defined to allow ready recognition of the echo as a cloud contact, usually coordinating the target course and speed with wind data, along with position angle, will enable the echo to be evaluated properly.

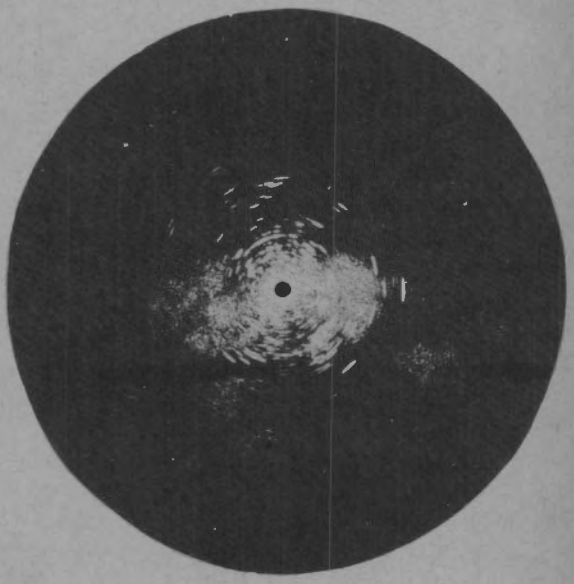
Since clouds often extend over several miles and may rise to heights of 40,000 feet, they produce echoes at extremely long ranges, and the echoes may cover large areas on the indicator. In some unusual cases, nearly the entire PPI scope may be so covered with cloud echoes that it is impossible to see targets. Because cloud echoes, like sea return, are longer than the echoes from more solid targets, both IAVC and FTC are of considerable use in minimizing interference from clouds. For example, figure 103A shows a large area of the SG-3 PPI scope obscured with cloud echoes. The clouds that cover the center of the screen are quite dense, but those at 3 o'clock and at 9 o'clock show the nebulous appearance characteristic of cloud echoes. In *B* the same conditions are shown except that the radar is transmitting a one-quarter microsecond pulse instead of a one-microsecond pulse. The increased resolution produced by this change reduces the density of the cloud echoes, but they are still troublesome. In figure 103C, the transmitted pulse duration is again one microsecond,

A. Receiver normal. No special circuits in.—1-microsecond pulse.



B. Receiver normal. No special circuits in.—1/4-microsecond pulse.

C. 1-microsecond pulse. IAVC switched on.



D. 1-microsecond pulse. Both IAVC and FTC switched on.

Figure 103—Cloud echoes on SG-3 PPI.

but the IAVC circuit is switched on and the cloud echoes are considerably cut down. With both IAVC and FTC connected in the receiver, the cloud echoes are reduced to almost negligible proportions (fig. 103D).

5. Atmospheric Noise.

The frequencies used for radar are so high that atmospheric noise, or static, has little effect on its operation. The noise which shows on the indicator is produced in the early stages of the receiver. However, strong pulses, similar to noise pulses, have been observed on meter-wave radar indicators as a result of nearby lightning strokes. On occasion 200 megacycle radar has encountered serious interference from St. Elmo's Fire. The Aurora Borealis, which interferes so greatly with most communications, seems to have no effect on radar.

CHAPTER V

LIMITATIONS INHERENT IN RADAR EQUIPMENT

A. Determination of range by radar:
Maximum range; minimum range; range accuracy; range resolution; reliability of radar ranges.

B. Determination of bearing by radar:
Bearing accuracy; bearing resolution; reliability of radar bearings.

C. Determination of altitude by radar:
Altitude accuracy; resolution in altitude; reliability of altitude determination.

D. Materiel factors:
Training of maintenance personnel; preventive maintenance; reliability of equipment; performance reports; echo box.

A. DETERMINATION OF RANGE BY RADAR

1. Factors That Affect Maximum Range.

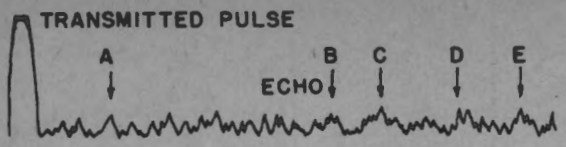
The maximum range at which targets can be detected by radar is affected not only by many characteristics of the equipment itself, but also by the operator and several other factors external to the set. Thus, the peak power transmitted by the radar, the duration of the transmitted pulse, the pulse repetition rate used, the efficiency of the lines that carry the pulse to the antenna, the height of the antenna above the water, the width of the lobe radiated from the antenna, the sensitivity of the radar receiver, and the type of indicator used in the set are a few of the most obvious characteristics of the equipment that affect range performance. Other factors external to the set at times exert a strong influence on the performance of the set. Among these are the skill and experience of the operator, the size, composition, and altitude of the target, the effect of reflection from the water, and the condition of the weather.

If the peak power transmitted by a radar is great, the power available for reflection back to the radar at any target that the pulse can reach will be greater than if a low-power pulse is sent out. However, it must be remembered that doubling the peak power of a set does not double the maximum range obtainable on a particular target; it increases the range only 20 per cent.

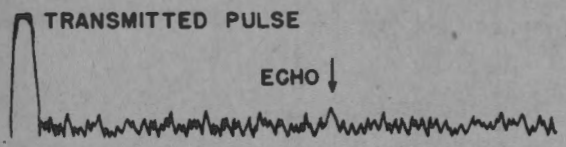
The full effect of pulse duration on maximum range is not thoroughly understood. It is apparent, however, that greater range can be obtained with a long pulse than with a short one. For this reason, many new radars are being designed so that they may send out long pulses when long-range detection is desired. The effect of increasing the pulse duration is made greater if the receiver is modified to accommodate the longer pulse duration. To reproduce a pulse, the receiver must amplify not simply a single frequency but a whole band of frequencies. The band is narrower the wider the pulse is made. Since noise voltages are spread more or less uniformly across an extremely wide frequency band, less of the noise is amplified by a receiver that is designed for a wide pulse than for a narrow one. As a result, a small wide pulse is more visible than a small narrow one not only because it makes a larger break in the trace, but also because the echo has less grass with which to compete.

The noise produced in a radar receiver is random in both frequency and amplitude. On a single sweep across an A scope, the noise voltage produces a rather coarse vertical deflection, like that shown in figure 104A. If during this single sweep a very small echo is returned to the radar, it will produce a slight vertical deflection of the trace which may be indistinguishable from large noise pulses. For example, it is impossible to tell in figure 104A whether pip *A, B, C, D,* or *E* is a real echo or a noise pulse. On the next sweep, the large noise pulses will appear at different places along the sweep because of the random nature of the noise, but the echo pulse will appear at the same position on the sweep as before. Since the echo pulse is retraced on each sweep, repetition of the sweep causes the echo pulse to be integrated both on the screen of the cathode-ray tube and in the eye and mind of the observer. The amount of this building up or integration is increased somewhat as the repetition rate of the radar system is increased.

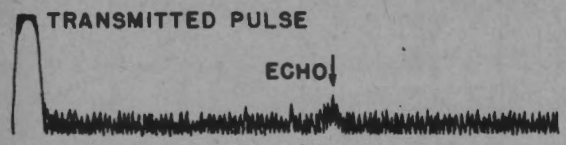
Since the noise pulses appear at entirely random positions on each sweep, they rarely coincide on successive sweeps. Thus, noise signals are not integrated, so that noise produces a rather evenly distributed background called grass, rather than a series of definite pulses. The effect of increasing the repetition rate is to cause the noise pulses to appear closer together, as in figure 104C, making the noise pattern on the screen become more solid. The size of the echo which is perceptible as a break in the solid



A. NOISE ON A SINGLE SWEEP



B. APPEARANCE OF NOISE WITH 2 SWEEPS SUPERIMPOSED



C. APPEARANCE OF NOISE WITH MANY SWEEPS SUPERIMPOSED

Figure 104—Receiver noise on Type A presentation.

pattern of the grass at a high repetition rate is smaller than the minimum perceptible echo in the coarser grass produced at a low repetition rate. This fact causes the maximum range at which a target can be detected to be somewhat greater as the repetition rate is increased.

The maximum range that can be measured directly by a radar is somewhat limited by the repetition rate used. For example, the interval between pulses is 610 microseconds for a 1640 cycle repetition rate. Within this time, the radar pulse can go out and back a distance equal to 610 *microseconds* × 164 *yards per microsecond* = 100,000 *yards*, which limits the length of the sweep, and therefore the maximum range that can be measured directly on the sweep, to 100,000 yards. Echoes from targets beyond this distance appear at a false range. Very high pulse repetition rates are undesirable, and are not used in Naval radar because of the limitation imposed on the maximum length of the sweep.

The energy that is radiated from the antenna is never as great as that produced by the transmitter because of the losses that occur in the transmission line. If coaxial lines are not airtight, moisture will accumulate in them, producing excessive attenuation. In waveguide similar difficulties can arise if the installation is not properly made. Recently some *P*-band radars have been fitted with solid-dielectric coaxial lines instead of the air-insulated copper pipe coaxial line used in all early installations. Tests indicate that the solid line has higher loss than the air-filled line when both lines are first installed. Since the solid line has no gas between conductors, it cannot breathe in moist air through a small leak when the temperature changes. As a result, the losses of the solid line remain nearly constant over long periods of time, because the insulation strength of the line remains high. In most cases, the losses of an air-filled coaxial line increase over a period of time because of the moisture that gradually works its way into the line. Thus, although the solid line may not be as efficient as the air-filled line at the outset, the solid line proves to be superior in the long run.

The range at which a given target can be detected increases as the square root of the antenna height. Thus, an air search radar with its antenna placed very high on the ship will detect more distant targets than a similar set with a low antenna, unless propagation conditions are non-standard. In some cases, the low antenna may be within a duct and the high antenna above it, causing the lower antenna to have better performance at that time.

If the antenna is made more highly directional, the energy of the transmitted pulse is concentrated into a smaller area. Thus the energy that strikes the target for a given transmitter output is increased by making the antenna beam narrower. A narrow beam can be obtained at a particular frequency only at the expense of increasing the size of the antenna. Since large antennas present difficult installation problems and because the need for stabilization becomes more pressing as the beam width is made narrower, it is necessary in designing a radar to strike a balance between the increased range possible with a highly directional array and the practical difficulties that arise from the narrow beam.

The more sensitive the receiver, the weaker may be the signal required to produce a visible pip on the indicator. As the sensitivity of the radar receiver is increased, then, the range at which a particular target can be detected is increased. The outstanding disadvantage of an extremely sensitive receiver is that it can be very effectively jammed rather easily, if it has not been designed with the necessary anti-jamming requirements clearly in mind. Usually the operator can detect small echoes better on an A scope than on a PPI because a signal that is hardly bigger than the grass on the scope is more visible as a break in the trace than as a faint spot on the screen. However, the advantage is not great enough to warrant sacrifice of the security of an all-around search in the hope of extending the maximum range of the radar a small amount.

In general, the larger the target the greater the range at which it can be detected. Land, particularly

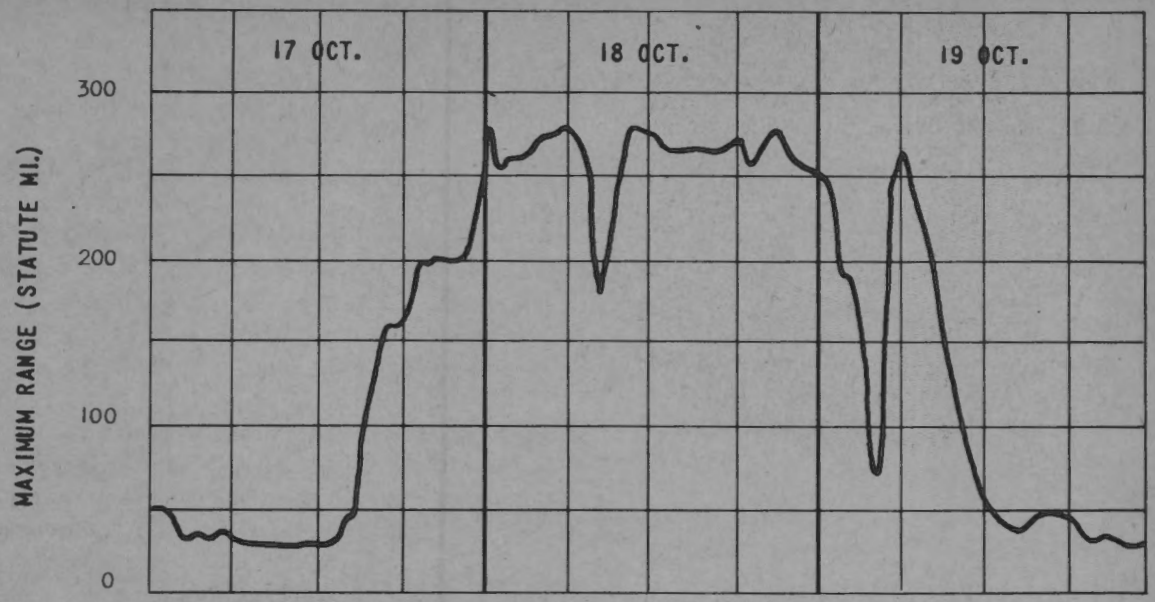


Figure 105—Variation in maximum obtainable range of a radar.

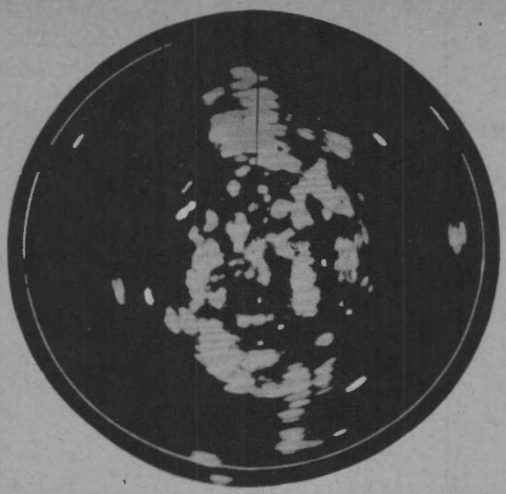
high, precipitous cliffs, can be detected at much greater range than any other type of target. Similarly, a group of planes can be detected at a greater range than a single plane because of the larger reflecting area. Targets at high altitudes can be detected at longer range than those at low altitudes simply because it is possible for the radar pulse to reach them. Low targets at long range usually are below the radar horizon, but nonstandard propagation may greatly extend the horizon.

The effect of varying propagation conditions is to make the maximum range obtainable with a radar a very variable quantity. For example, figure 105 shows a portion of the recorded maximum ranges of an S-band radar for a constant level of performance of the set. The average maximum range is 60 miles, but the longest range is as great as 280 miles.

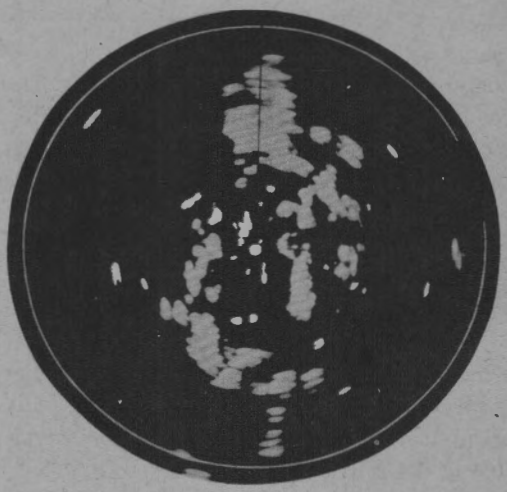
2. Factors That Affect Minimum Range.

The minimum range at which radar can detect a target is controlled primarily by the length of the transmitted pulse. Some of the energy of the transmitted pulse leaks directly into the receiver, which overloads the receiver, causing it to be blocked or paralyzed. At the end of the transmitted pulse, the receiver begins to recover, but the recovery is not instantaneous. As long as the receiver is blocked, a saturation signal appears on the indicator, and no echo pulses can be seen during this time. Most receivers require a time roughly equal to the pulse duration to recover normal sensitivity after being blocked by the transmitted pulse. Thus, no echoes can be seen for a distance represented by approximately twice the pulse duration. For example, the minimum range of a radar using a two-microsecond pulse will be approximately 2×2 *microseconds* $\times$ 164 *yards per microsecond* $=$ 656 *yards*. Recent advances in receiver design have reduced the recovery time to a very small value, so that normal sensitivity is regained almost as soon as the transmitted pulse ends.

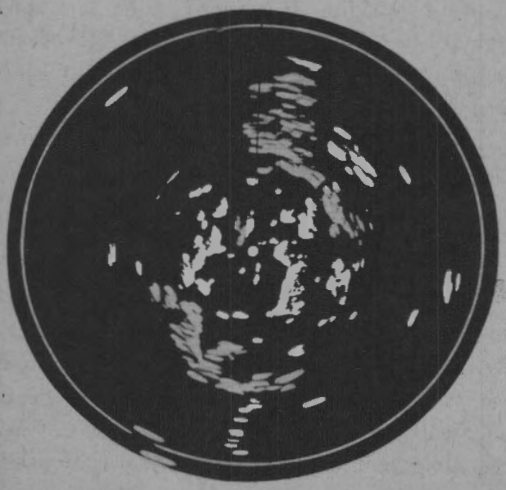
Since sea return produces a clutter of varying echoes near the start of the sweep, the minimum range at which real targets can be detected is dependent on the extent of the sea return. In rough water the sea return will be strong and may extend three miles from the radar, preventing the detection of targets within this distance. When the radar is operated within a few miles of either land or large ships, targets cannot be tracked in to a short range because side-lobe echoes clutter the first mile or two of the sweep irrespective of the direction to which the antenna is trained. However, since targets within the area covered by sea return generally produce very strong echoes, the receiver gain may be considerably reduced so that the echoes will stand out from the sea return. Sensitivity-Time Control (STC) is a modification of the receiver by which the receiver gain is reduced for the first few thousand yards of each sweep and then restored to normal for the remainder of the sweep. The reduced gain at short range provided in this modification should prove to be of value not only in lessening sea return, but also in preventing side lobe echoes returned by nearby large targets from obscuring the start of the trace. For example, the appearance of the PPI on the modernized SG is shown in figure 106. In *A* all special circuits are disconnected, but the new 7-inch cathode-ray tube is used instead of the 9-inch tube originally furnished, resulting in increased definition. In *B*



A. Targets on PPI screen with special circuits disconnected. Photographed on the new 7" cathode-ray tube.



B. Targets on PPI screen showing effect of new STC circuit. Note the clarity of the presentation near the center of the screen.



C. Targets on PPI screen after completion of modernization. Combined effects of STC, IAVC, and FTC are shown. Note that large objects are broken up into smaller parts, and that range resolution is somewhat improved.

Figure 106—Modernization of SG radar.

the Sensitivity-Time Control circuit is connected, so that the clutter of sea return is removed but the ship targets at short range are still visible. Note that the patterns are practically identical in *A* and *B* with the exception of the centers. The pattern is further clarified in *C* by the connection of IAVC and FTC in the receiver.

The minimum range to which high-flying airplanes can be tracked is dependent on the vertical coverage of the radar antenna. In general there is but little

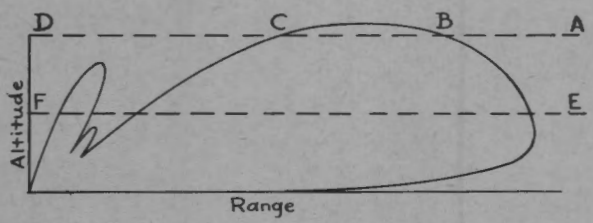


Figure 107—Vertical coverage of air search radar antenna.

energy radiated directly overhead or at large position angles, although some new systems will provide good cover overhead. The curve shown in figure 107 is the envelope of the lobes produced by water reflection, and it represents the points at which an airplane can be detected. If the plane flies along *ABCD*, it will be detected initially at *B*, and the radar can track it between *B* and *C*. At point *C*, the plane will fly out of the antenna field, and will no longer be detected. At a lower altitude, such as *EF*, the plane can be followed to a much shorter range.

Air search radar antennas usually have fairly wide beams in the vertical direction so that they will be able to detect planes to large position angles. As a result, the maximum position angle at which airplanes can be detected seldom imposes a serious limitation on the minimum range of this type of radar. On surface search radars, however, the vertical coverage is rather limited. Consequently, high-flying airplanes are not detected, and all except low planes are usually lost before they approach close to a surface search radar.

The minimum range of a radar depends, therefore, principally on the duration of the transmitted pulse and the receiver recovery time. However, sea return and the antenna radiation pattern affect minimum range to a great extent. It is evident from figure 107 that minor lobes of radiation in the vertical direction are beneficial in allowing the radar to detect high flying aircraft close in to the set.

3. Factors That Affect Range Accuracy.

The accuracy with which radar can measure range is dependent on the precision with which the time interval between the transmitted pulse and the echo pulse can be measured. In fire control radar very accurate range data are required. As a result, radars designed for this purpose are complicated by the equipment necessary for measuring precisely the extremely short intervals of time involved. Since search radars are not required to furnish highly accurate range data, relatively simple ranging methods are used.

One factor which affects the precision of range measurement is the ability of the operator to align the range marker with the echo pip. On long range scales, it is difficult for the operator to align the pip and range marker precisely, because small changes in the range knob do not cause perceptible changes on the scope. Thus, the range accuracy of radar varies with the range scale used. In general, the longer the range scale, the less accurate the ranges.

To avoid this limitation, most fire control radars employ an expanded sweep. The expanded portion of the sweep can be centered on the desired echo, so that the precision with which the range marker and echo can be aligned is constant over the whole range of the system. In the Mark 8 fire control radar, the average operator is able to align echo and range marker within 15 yards. In several fire control radars the range marker can be made to move automatically at a rate controlled by the radar operator. This system, which is called aided tracking, can be very helpful in producing a smooth track on targets. An advance over this system is automatic range tracking, such as the system supplied in the Mark 12 radar. Because the electronic system is capable of operating on differences that are smaller than those perceptible to the operator, automatic range tracking can indicate the range of a target more accurately and more consistently than the operator can. Full automatic tracking in range, bearing, and position angle is possible in the laboratory, but production equipment is not yet available to the fleet for this purpose.

If the radar operator is to be able to measure range precisely, the range marker must produce a very sharp break in the sweep trace, and the echo pulse must be very sharply defined. If the pulse rises sharply, the pulse duration has little effect on the range accuracy. Thus, it is possible to obtain more precise range data from a precision PPI connected to a search radar than from the radar itself. This increased accuracy results from the use of an expanded sweep and circuits capable of highly accurate time measurement in the precision PPI.

Errors in ranging can also be caused by slight variations in the frequency of the oscillator used to divide the sweep into equal range intervals. If such a frequency error exists, in general the ranges read from the radar will be in error by some small per-

centage of the range. In the Mark 8 or Mark 12 fire control radar, the range accuracy is given as ± 15 yards ± 0.1% of the range. The first term, ± 15 yards, represents the fixed errors in the system plus the error of aligning the echo and reading the dial. The second term expresses the error that may be introduced because of the tolerance in the oscillator frequency. The maximum error in the range reading for a target at 30,000 yards would then be ± 45 yards.

In order to reduce range errors caused by frequency drift, precision oscillators in radars are usually placed in a constant-temperature oven. Since the oven is always heated, there is no drift of range accuracy while the rest of the set is warming up.

In fire control radar it is necessary to eliminate the fixed error that exists because of delays in the system. The zero reference for all range measurement must be the leading edge of the transmitted pulse as it shows on the indicator. Since part of the transmitted pulse leaks directly into the receiver without going to the antenna, the time required for r-f energy to go up to the antenna and to return from the antenna to the receiver as an echo constitutes a fixed error. This error causes the indicated ranges to be greater than their true values. To compensate for this error and for other delays in the system, a negative Zero Set must be applied to the indicator. This correction can be determined by methods discussed in the Radar Maintenance Bulletin, and it should be redetermined periodically to guard against change.

This same fixed error was found to be appreciable in search radars when the VF precision repeater PPI, with its accurate ranging circuit, was installed. A device called a Trigger Delay circuit was therefore developed to eliminate the error. By this means the trigger pulse to the indicator can be delayed a small amount, in steps of 0.05 or 0.1 microsecond, in order to cause the sweep to start not at the instant that the pulse is generated in the transmitter, but at the instant that an echo would return to the indicator from a flat plate right at the antenna. Once the trigger delay is properly set, it should need no further attention, other than periodic checking to insure that the sweep actually starts at the true zero instant of the radar.

The accuracy of range measurement is dependent on the constancy of the line voltage supplied to the radar equipment. If the supply voltage varies more than approximately ten per cent from its nominal value, the ranges indicated on the radar may be unreliable. Such a condition is likely to arise when the turrets are put in motion if the radar power is taken from a common supply. In some installations it has been found necessary to supply the radar power from a separate source to prevent variation in range accuracy. However, in many cases, large line voltage fluctuations can be absorbed in a constant voltage transformer. If proper precautions are taken, variations in supply voltage need not affect the operation of the radar.

It is usually necessary to maintain station in a high speed formation within 300 yards and 3° of the assigned range and bearing from the guide in order to insure safety. Since search radar is not designed for a high degree of accuracy, it is difficult to keep station within these limits directly from the master PPI or a repeater PPI on the bridge. Consequently, in the past it has often been found necessary to restrict one surface search radar exclusively to station keeping by operating it in manual train, so that the superior accuracy of the type A indicator could be used. The precision repeater PPI should be of great assistance in station keeping because the range and bearing of the guide can be continually observed on the type B scope while the whole formation can be observed on the PPI. The precision PPI will therefore permit the surface search radar to be used simultaneously for both station keeping and other purposes, and will permit station keeping well within safe limits.

On many PPI scopes range can only be estimated by reference to range circles which are either produced electronically or scribed in a plastic overlay on the screen. Range can be estimated at best within one per cent of the sweep length by this means, but a more reasonable accuracy to expect would be on the order of two or three per cent. Thus, the error in the estimation, in yards, is a function of the range scale in use. If the PPI is set to the 40-mile scale, the range of a target should be within 150–250 yards of the value called off by the operator. However, if an 80-mile scale is used, the ranges determined are within only 3,000–5,000 yards of the true range. As a means of reducing this error, a range ring is being provided on many PPI scopes. The diameter of this ring is variable by the operator in the same way that the range step on the A scope is variable in position, and the ring is used for the same purpose. Such a range ring is being provided on the SG-1 radar, for example, as part of the modernization program for this equipment.

4. Factors That Affect Range Resolution.

The principal factors that affect the range resolution of a radar are the width of the transmitted pulse, the receiver gain, and the range scale. For a high degree of range resolution, a short pulse, low receiver gain, and a short range scale are required.

Radio frequency energy travels through the atmos-

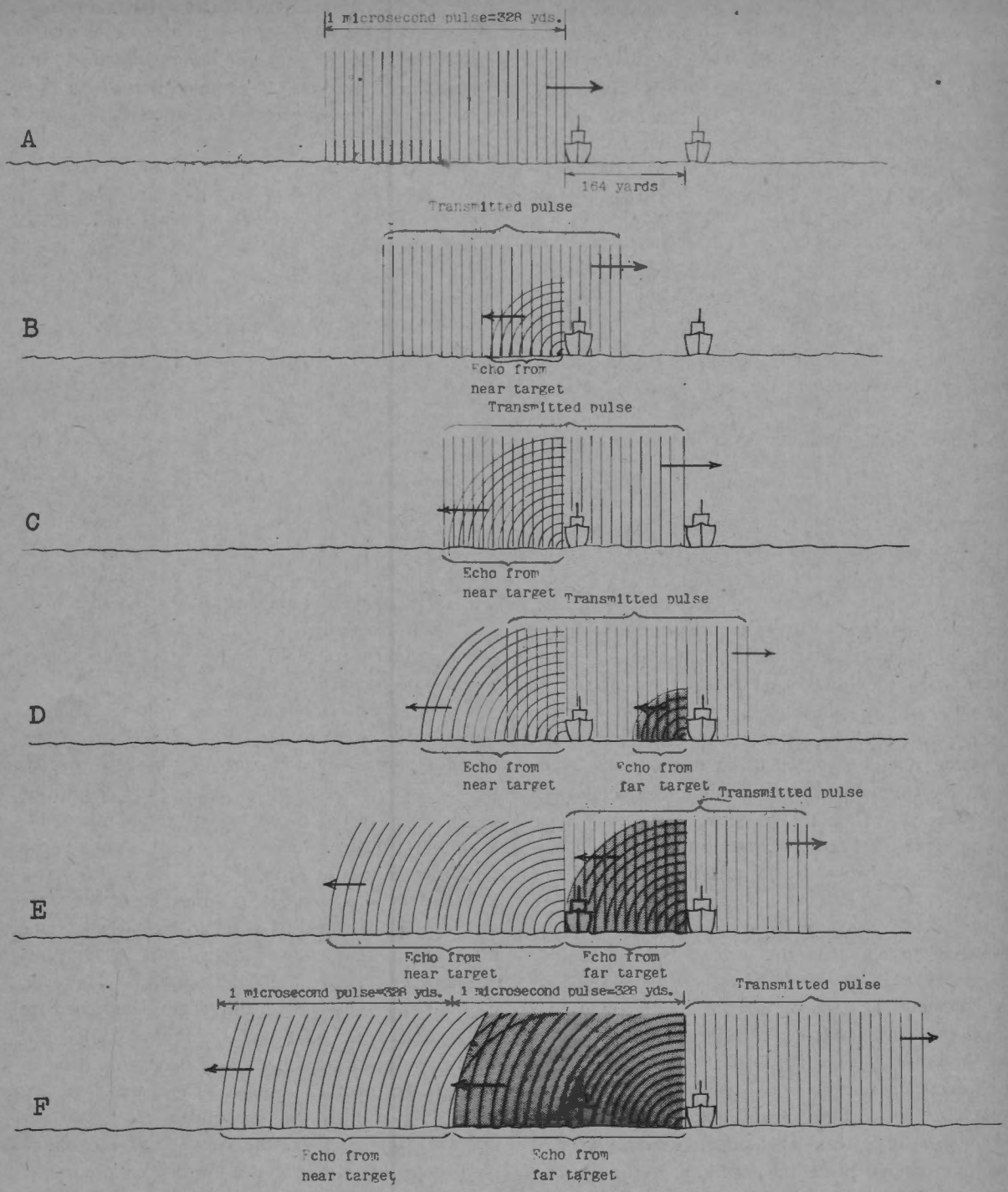


Figure 108—Illustration of minimum target separation required for range resolution.

phere at the rate of approximately 328 yards per microsecond. Thus the end of a 1-microsecond pulse travelling through the air is 328 yards behind the leading edge, or start of the pulse. If a 1-microsecond pulse is sent toward two objects on the same bearing that are separated by 164 yards, the leading edge of the echo from the distant target will coincide with the trailing edge of the echo from the near target in space. As a result, the echoes from the two objects blend into a single pip, and range can be measured to only the nearer object. The reason for this blending is illustrated in the idealized drawing in figure 108.

In *A* the transmitted pulse is just striking the near target. In *B* energy is being reflected from the near target while the front of the transmitted pulse continues toward the far target. At *C*, one microsecond later, the transmitted pulse is just striking the far target, while reflected energy from the near target

has travelled 164 yards back toward the radar. The reflection process at the near target is only half completed. At *D*, echoes are travelling back toward the radar from both targets, and at E reflection is completed at the near target. Notice that at this time the leading edge of the echo from the far target has returned as far as the near target, so that it just coincides with the trailing edge of the first echo. In *F* reflection is completed from both targets, and the transmitted pulse continues beyond them, while an echo of twice the normal width returns toward the radar. When the echoes reach the antenna, energy is delivered to the set during a period of 2 microseconds, so that a single wide pip shows on the indicator.

Since energy is reflected from the target for the duration of the transmitted pulse, even a flat piece of sheet iron will appear to be 164 yards wide on the indicator, with a 1-microsecond transmitted pulse. Thus, the width of the echo from any target will appear to have on the indicator a width in yards at least equal to 164 *yards per microseconds* × pulse duration *in microseconds*. Ideally, then, the minimum separation between two targets that will permit the indicator to resolve their echoes into two distinct pips is the range represented by the duration of the transmitted pulse. In practice, the separation required must always be greater than this value because of the influence of other factors in the set.

Although the pulse width is the primary factor in determining range resolution, the receiver gain used is also of great importance. This is especially true on equipment in which either a type B or PPI indicator is used. It is assumed that the pulse sent into the receiver is perfectly square, but in general the output pulse will be somewhat distorted. The approximate

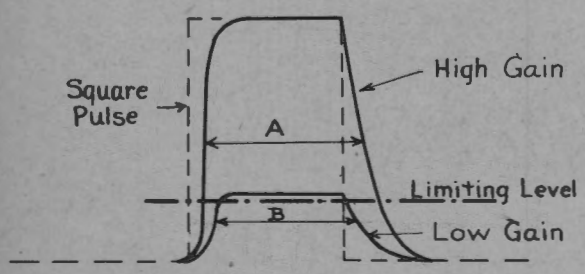


Figure 109—Echo pulse shape.

shape of the output pulse is shown in figure 109. The width of the pulse at the base is nearly constant for all gain settings, but the apparent width at the middle of the pulse is greater the higher the gain is set. (Compare widths *A* and *B* in fig. 109.) As a result, if the gain is reduced when it is desired to resolve two echoes, the minimum range separation between the targets may approach the ideal limit of the distance represented by the pulse length.

In most PPI and type B indicators the amplitude of the echo pulse applied to the cathode-ray tube is limited at some definite value. If limiting takes place at the level indicated in figure 109, it is at once apparent that receiver gain exerts a direct control on the size of the spot of light produced on the screen. If very high gain is used, the spot will be larger than if the receiver gain is low. Thus, the echoes from two targets which are close together may merge into a single large bright spot at high gain, but they may separate into two definite spots at low gain.

A third important factor in determining the range resolution of the radar set is the range scale used. On a long range scale, a separation of a few hundred yards will not be apparent, and two adjacent pips will seem to blend into one. However, if these same echoes can be displayed on a short range scale, as on an expanded sweep like that provided on an R scope, the small separation will be visible.

Ideally, the electron beam in a cathode-ray tube can be focused to a point of light; actually, the point of light has a definite diameter. If the beam cannot be focused to a very small spot, the range separation required for resolution is increased because the indication on the screen is not well defined. In addition, there is a small amount of fringing on some cathode-ray tubes which causes the edges of the spot to be hazy. In general, large cathode-ray tubes do not permit a very great improvement in definition of the pattern because the spot size increases almost in proportion to the tube size. In fact, the spot size on some of the larger PPI tubes is larger in proportion than on smaller tubes. Until recently, tubes larger in diameter than 7 inches offered no improvement in definition. For example, the 9-inch cathode-ray tube used in the SG radar was found to produce a poorly defined pattern on which advantage can not be taken of the resolution of which the radar is capable. To remedy this deficiency, the SG PPI tube has been reduced to a 7-inch cathode-ray tube in the modernization program promulgated as Change No. 50 for this radar.

The physical size of the indicator tube has a very definite effect on the range resolution of a radar. For example, on a 12-inch PPI using a 200-mile range scale, the sweep is 6 inches long and approximately 2,500 microseconds in duration. On such a sweep, 1 microsecond can occupy only 0.0025 inch. If the minimum spot size that can be produced on the tube is 0.03 inch in diameter, then the spot itself must appear to be a mile in diameter on this range scale. In such a case it is apparent that the trans-

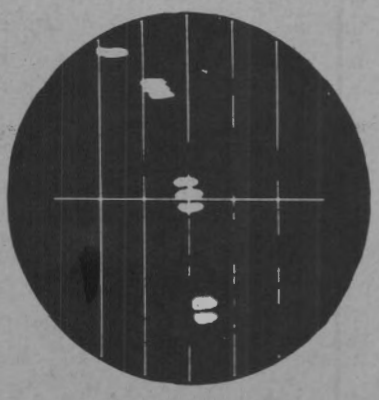
mitted pulse no longer controls range resolution. If the same range scale is used on a 5-inch cathode-ray tube, the spot is nearly 2.5 miles in diameter. Thus, on long range scales it is impossible for the PPI to paint a sharply defined image on which targets may be easily resolved, just as it is impossible to paint small letters with too big a brush. However, when the range scale on the 12-inch tube is reduced to 20 miles, the spot diameter is only 200 yards, although it is physically still the same 0.03 inch in diameter. The effect on range resolution of an R scope, or of any expanded presentation, then is not only to spread adjacent echoes so that the separation between them is apparent, but also to allow the cathode-ray tube to paint the picture with a fine brush so that the pips are clearly defined. The delayed and off-center PPIs, which are expanded PPI presentations, are discussed in chapter VIII.

For a high degree of range resolution, a short pulse duration, low receiver gain, an expanded presentation, and a cathode-ray tube capable of good definition are required. In air search radar, the resolution is usually only fair because no provision is made for an expanded sweep, but the newer air search radar equipment will have an expanded sweep. Most fire control radars have good range resolution because of the expanded sweep that is provided to insure accuracy, and because the transmitted pulse duration is short.

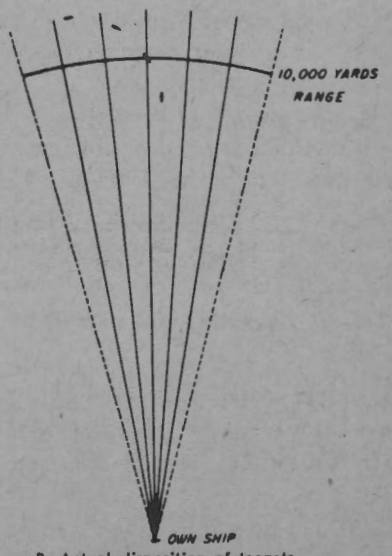
Although the operator may not be able to range on either target at will, he can nearly always tell from the character of the echo when two or more targets are present at nearly the same range and bearing. If the targets are ships, for example, they roll independently, so that their echoes fade at different rates.

Because of the high degree of range resolution of the Mark 8 radar, it has been found possible to estimate target angle on large battleships at ranges up to 15,000 yards. Apparently the stern and bow masses give weak echoes which fade out at ranges greater than 15,000 yards but the large foremast structure gives a strong echo to ranges of 30,000 yards or more. Thus at target angles other than 000°, 180°, 090°, and 270° a battleship of the *South Dakota* class appears as three separate signals. The third signal is masked by the foremast structure at target angles of 000° and 180°. At 090° and 270°, except at short ranges, the three signals blend into one because there is insufficient angular separation between the three masses on the ship. Theoretical Mark 8 patterns for target battleships of the *South Dakota* class are shown in figure 110*A* for target angles of 000°, 030°, 060°, and 090°. Figure 110*B* shows the actual disposition of the four ships. An experienced operator can estimate target angle within 10° from observation of the Mark 8 screen.

A cruiser appears as two signals except at target angles of 090° or 270°, when the echoes from the bow or stern and foremast structure blend into one signal. An aircraft carrier appears as two signals at all target angles due to the offset structure. Hence, it is difficult to estimate target angle on ships of these classes. A destroyer appears as a single signal which fades in and out as the target rolls and pitches in the seaway. With radar equipment having poorer range resolution than the Mark 8, it is not possible to estimate target angle, even on large ships.



A. Presentation on scope.



B. Actual disposition of targets.

Figure 110—Target angles shown on Mark 8 radar.

5. Reliability of Radar Ranges.

Since it is not possible for the radar operator to recognize the target on which he is ranging by any means other than interpreting the pattern that he sees, it is possible for him to range on the wrong object. This weakness opens the way to the use of certain deceptive countermeasures by the enemy. However, with a properly functioning CIC and an adequate system of indicating targets, mistakes of this sort can be considerably reduced and probably eliminated. Intensive training of the radar operators will also help to keep such errors to a minimum.

An operator usually can see enough of his target in an optical rangefinder to avoid ranging on the wrong one. However, radar ranges are more accurate than optical ranges, especially on targets beyond 10,000 yards, so that the radar data are more dependable in spite of the lack of target recognition.

B. DETERMINATION OF BEARING BY RADAR

1. Factors That Affect Bearing Accuracy.

If radar could be used only against isolated, single targets that were either stationary or moving slowly, accurate bearings could be measured relatively easily. However, where targets move fast it is difficult to keep the radar beam aimed properly, and therefore impossible to realize the full accuracy of the radar. Several targets close together may return echoes that the radar cannot resolve, which prevents the determination of accurate bearing on any single target within the group. When the target is isolated and not moving too fast, the accuracy with which its bearing can be determined by radar is dependent on: the width of the antenna beam, whether lobe switching is used or not, the type of presentation on which the echoes appear, the size of the target, and the care with which the antenna is aligned with the ship's head when it is installed.

In a radar system which radiates its energy in a single lobe, only moderate bearing accuracy can be obtained. The end of the lobe is rather broad, so that a small change of antenna train produces an imperceptible change in echo height when the axis of the beam is near the bearing of the target. For example, signal strength *B* in figure 111 is only a little less than signal strength *A*, so that the echo height on an *A* scope would be nearly the same whether the target were at position *A* or position *B*. If a very narrow beam is used, bearing can be determined rather precisely. However, a beam that is narrow both horizontally and vertically, as in the SM or SP radar, is not very effective for use in searching for aircraft, although it may be used to advantage to scan the horizon for low-flying planes and ships. If an air search radar is to measure bearing accurately and yet be able to detect aircraft at any altitude, the beam must be shaped like a fan—narrow in the horizontal dimension and wide vertically. Many of the new search radars, such as the SR-3, SX and SV, will have beams of this shape.

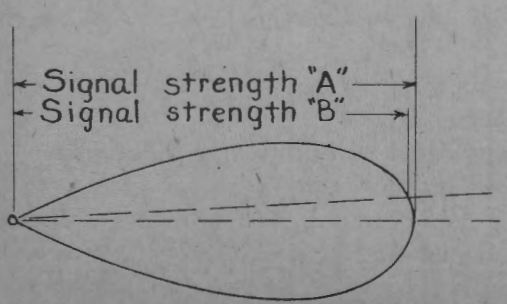


Figure 111—Accuracy of a single lobe.

Since the radiated beam has appreciable width, energy is reflected back to the radar over a definite angle. In figure 112A, if the echo is barely perceptible along *OA*, the echo will increase in size as the antenna is rotated to bring the lobe axis on target. The echo is a maximum at *B* and it just disappears at *C*. If this echo is displayed on a PPI scope, it will appear as an arc equal in length to the beam angle plus the angle subtended by the target.

Instead of attempting to train the antenna so that the target lies along the lobe axis *OB* in figure 112, better accuracy will result by determining the bearings at which the echo disappears, and then taking the mean of these values as the bearing of the target. In this method, the antenna is rotated manually first to the left until the echo disappears at *A*, and then to the right until it disappears at *C*. The average of the bearings along *OA* and *OC* is the bearing of the target, determined more accurately than can be found by simply maximizing the echo. However, this method is slow and it requires that the antenna be swung over a limited sector instead of being kept in constant rotation. The slowness is also a handicap when the target has a high rate of change of bearing, for within the time required to find the two "cut-out" bearings the actual bearing of the target may have shifted.

The fact that energy is received over a definite arc of antenna rotation causes all echoes on a B scope to appear as lines. Since the sides of the lobe are steep, the ends of the line produced by an echo on a B scope are well defined. Most people are able to bisect a straight line with a surprising degree of accuracy. If this ability is applied to bisecting the line produced by an echo on a B scope, the bearing of the center of the echo can be rather accurately determined. The excellent bearing accuracy possible with the precision PPI and the Mark 8 fire control

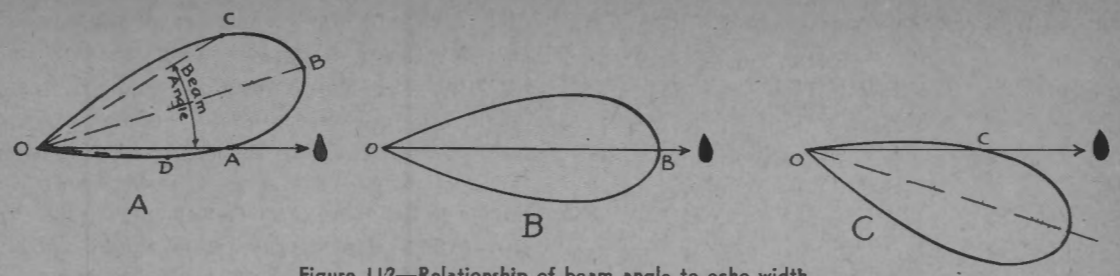


Figure 112—Relationship of beam angle to echo width.

radar depends on this principle. The same process can be applied directly to a PPI scope if a cursor is provided with which to bisect the echo arc. However, the accuracy of bearing determination on the PPI scope varies with range because the length of an arc of a given angular length is directly proportional to the radius of the circle on which the arc is drawn. The ability to bisect the arc accurately suffers if it is either too long or too short. Determining bearing by bisecting the arc on a PPI or the line on a B scope is exactly the same process as determining bearing on an A scope by finding "cut-out" bearings. However, the intensity-modulated presentations have the advantage of allowing the determination to be made quickly without the need for stopping the antenna.

Since most radars send out their pulses in a single lobe, they are not capable of determining bearing with a high degree of precision. Air search radars operate on lower frequencies than surface search radars, so that the beam width of the air search radar is considerably broader than that of the surface search radar. It is for this reason that the bearing accuracy of the SK is poorer than that of the SG.

The size of the echo returned from a target varies with the orientation of the antenna lobe relative to the target. The rate of change of echo size per degree of rotation of the antenna is greater at the side of the lobe, as in the vicinity of point A in figure 112, than at the end of the lobe. If the antenna is designed so that the lobe can be switched continuously from side to side of the optical axis of the antenna, use can be made of this high rate of change of echo size with bearing as a means of measuring bearing accurately. Such a scheme is called lobe switching, and the pattern produced by the antenna is like that shown in figure 10. The bearing accuracy of a lobe-switching system increases as the lobes are made narrower, because of the increased sensitivity to a small change of antenna position. This system is used in many fire control radars because it allows bearing to be measured very precisely.

The comparison of the echo height from the left-hand lobe with that from the right-hand lobe gives the operator a sense of direction by which he knows the direction to train the antenna to bring it on target. This sense of direction is furnished by a special indicator presentation which may be any one of several types. The earliest form displayed the echo from the right lobe displaced horizontally from the echo from the left lobe, as in figure 10. This allows the two pips to be adjusted to the same height by training the antenna to the bearing of the target. An experienced operator can match pips very accurately, thereby determining the bearing of the target accurately. Another type of indicator used for the same purpose is the target spot indicator described in chapter II, and a third kind of indicator uses a meter on which the needle indicates the direction in which the antenna axis is off target or if the antenna is correctly on the target bearing.

Many targets are so large in extent that they subtend large angles at the radar antenna. For example, a cloud or a land mass may cover an angle of as much as 40° at ranges less than 10,000 yards. The trainer's pips can be matched over this whole angle if the shoreline is at nearly the same range. As a result, it is often impossible to get a bearing on a land mass with a lobe switching radar system. A plan position indicator is of much greater utility against such a large target because it shows irregularities much more clearly, enabling the bearing of prominent objects to be determined.

The high degree of precision in measuring bearing that lobe switching provides can be used only when time is available to match pips carefully. Therefore, bearings measured in this way on nearby aircraft will be considerably less accurate than bearings on stationary targets.

The angle over which the antenna can receive any energy is dependent on the beam width. If the beam is oscillated back and forth, the antenna can receive signals over a wider angle. Thus, it is easier for the enemy to jam a radar when the lobe switching is operating than when a single lobe is used because the ability of the antenna to select the direction from which it receives energy is reduced. In a lobe switching system jamming also may have the effect of producing large bearing errors by reinforcing only one lobe instead of affecting both lobes equally.

If the fire control system is to take full advantage

of the accuracy possible with a lobe-switching radar, the optical axis of the radar antenna must always be parallel to the optical axis of the director. It is sometimes found that vibration and the shock of gunfire cause the antenna to get slightly out of alignment. Since it is desired to determine the bearing of a target within a few mils, very slight misalignment of the antenna can produce a significant error. To guard against this error, the agreement between optical and radar axes should be checked frequently by observing the target through the trainer's telescope the instant that the radar indicates on target.

Frequently part of the superstructure of the ship is within the radar beam on some relative bearings. The interference produced by the part of the pulse that is reflected by the superstructure may badly distort the antenna pattern. In extreme cases, the axis of the lobe may be skewed as much as 7° by structural reflections. Obviously if the axis of the antenna beam is not along the optical axis, errors in bearing will be introduced that vary with relative bearing. Careful installation should minimize such errors, but when several antennas are installed on one ship, it is not possible to avoid interference with the beams of some of them on some bearings.

2. Factors That Affect Bearing Resolution.

When two targets are separated by a small angular distance, radar cannot determine the bearing of either target. The minimum angular separation required between targets to permit the radar operator to determine the bearing of either target is termed the bearing resolution. The magnitude of this angle is dependent primarily on the effective beam width of the radar antenna. The effective width of the antenna beam, however, is not a constant quantity, since it is affected by the receiver gain, the size and range of the target, and whether lobe switching is turned on or not. Bearing resolution is affected also by the type of indicator used to view the echoes.

The lobes shown in figure 113 are plots of the echo size received by the radar as functions of the bearing of a target relative to the lobe axis. If momentarily lobe ② is considered to be a plot of the power radiated by the antenna in various directions, the lobe indicates the shape of the area illuminated by a pulse. Generally the width of a radar beam is said to be the angle measured between the two directions along which the power radiated is half that radiated along the lobe axis. Thus, for the antenna whose lobe patterns are shown in figure 113, the conventional lobe width is the angle *DAG*. However, the effective lobe width over which echoes can be received is not simply this constant value.

If a target lies on the lobe axis, and the receiver gain is varied, the size of the received echo will also vary. For high gain, the echo will be proportional to the line *AM*, for medium gain to *AL*, and for low gain the echo will be small and proportional to *AK*. The minimum perceptible echo signal for this radar is indicated in the diagram by the dashed circle. Thus, at high gain the radar can see the target if it is within the angle *BAC*, since all echoes received in lobe ③ within this angle are larger than the minimum that can be detected. When the gain is reduced to a medium, more normal setting, visible echoes can be received over the slightly narrower angle *DAG*. At low gain the effective width over which echoes can be received is only *HAJ*.

The effect of the size and range of the target on echo height is very similar to that of the receiver gain. Either large targets or very close targets return strong echoes which may be received over a wider angle than normal. Similarly, distant targets or small

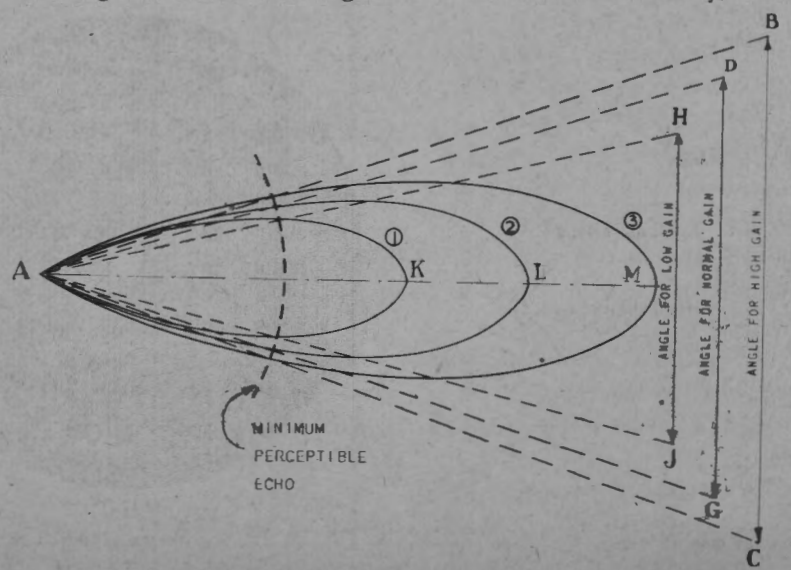


Figure 113—Variation in effective beam width with receiver gain.

objects return relatively weak echoes that can be received over only a narrow angle.

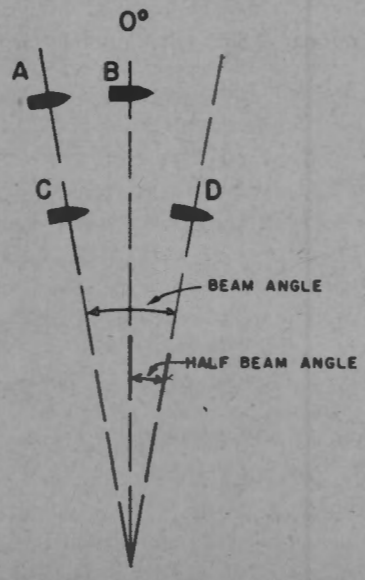
With normal receiver gain, a target at medium range along bearing *AD* produces a barely discernible echo, while one along bearing *AL* produces a strong return. Thus, if two targets are at the same range but separated by an angle equal to or greater than *DAL*, the radar operator will be able to determine the bearing of either without interference from the other if he looks on an A scope. It is apparent, then, that the bearing resolution angle of the radar is equal to half the beam angle of the radar under these conditions. However, the resolution is poorer than this value for large targets at short range or when the receiver gain is excessively high. If such targets are to be resolved, the receiver gain must be reduced, but this adjustment may not allow a long-range search to be conducted at the same time. Sensitivity-Time Control, which automatically reduces receiver gain for the first few thousand yards of the sweep, will therefore be useful in improving bearing resolution at short range, while allowing an adequate search to be maintained.

Although the minimum angular separation necessary for bearing resolution decreases to some extent as range increases, the separation in yards required to resolve the echoes increases with range. For example, if the minimum angle required for resolution is 4°, the targets must be separated by 1,000 yards if they are both at 15,000 yards range. However, at 40,000 yards range, the resolution angle may be reduced to 3°, but the necessary target separation becomes 2,100 yards. In general target separation required for bearing resolution is greater than that required for range resolution.

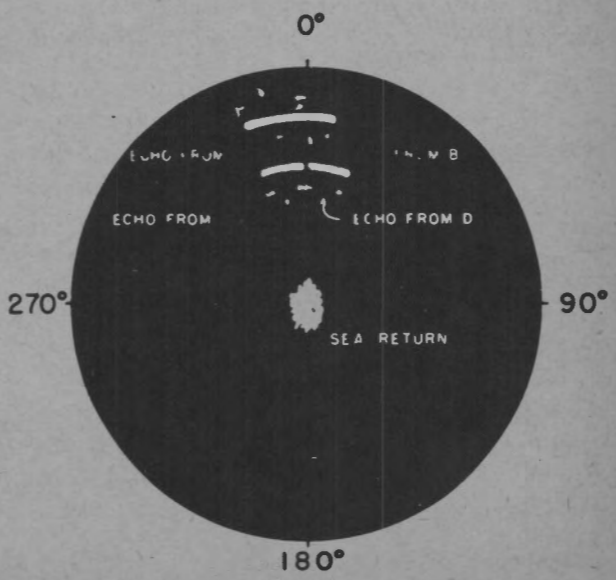
On a B or PPI presentation an echo appears as a line or an arc which is approximately equal in length to the beam width plus the target width. Thus, if two targets are separated by only half of the beam width, the echoes will blend into a single bright trace. As a result, the minimum angular separation required for resolution on a type B or PPI presentation is nearly twice the value for type A presentation. In figure 114, ships A and B are separated by half the beam angle, so that their echoes overlap. Ships C and D are separated by the full beam angle, making it possible to detect a space between their echoes. However, other factors, such as target motion and selective signal fading, may make resolution possible for angular separations somewhat less than the full beam width on indicators of this type.

The moving spot type of indicator used in several fire control radars is considerably affected by the resolution of the equipment. If the echoes from only a single target are allowed to control the position of the spot relative to the crosshairs, the moving spot indicator can show satisfactorily the bearing and position angle of the target relative to the "line of sight" of the antenna. However, if two or more targets are within the minimum angle required for resolution, all their signals affect the position of the spot, and it does not then show an accurate indication of the actual position of the target. In general, if there are two targets within the resolution angle, the spot will indicate a position between the targets.

When lobe switching is used, the effective beam width of the antenna is increased over the width of the beam proper. For example, in figure 115, the actual beam width is 11°, but since the lobe is shifted 4° to both right and left, energy is spread



A. Actual disposition of targets.



B. Appearance of targets on PPI.

Figure 114—Bearing resolution on PPI presentation.

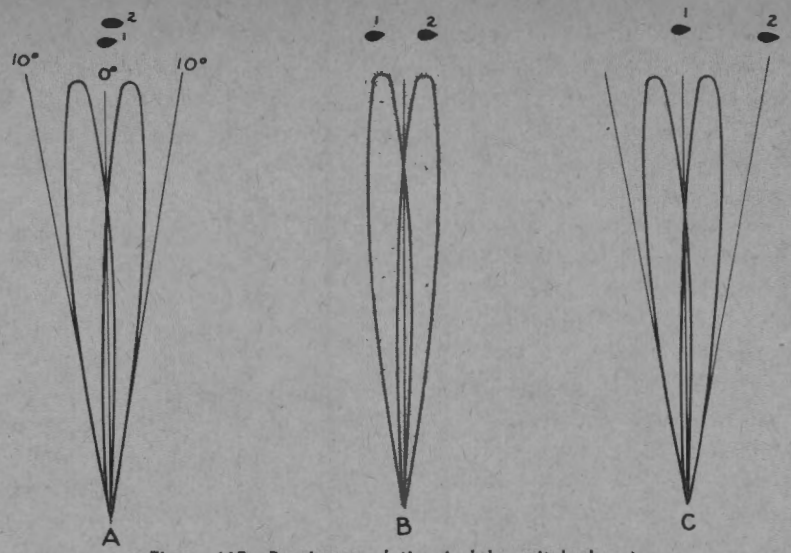


Figure 115—Bearing resolution in lobe-switched system.

over nearly a 20° angle. The minimum angular separation of targets required for resolution in this case, which is representative of the Mark 4 fire control radar, is 10°.

The range difference between targets 1 and 2 in figure 115A is sufficient to allow only the echoes from target 1 to be observed on the trainer's scope. Therefore, an accurate bearing can be obtained on target 1 in spite of the fact that target 2 is separated in bearing only by a small angle. However, if the targets are at the same range, but separated in bearing by 3° or less, the pips can be matched over the whole 3° angle, giving the effect of a single elongated target. When the angular separation between the two targets is between 3°–6°, a spurious echo seems to be approximately midway between the two real targets. If the trainer matches pips on the spurious echo, the antenna will be directed at neither target but at some point between them (fig. 115B).

The tendency for the trainer to direct the antenna to a point between the target persists until the target separation exceeds 10°. Matching pips is somewhat erratic at angular separations less than 10° because the targets roll independently, causing the echoes to fade unequally. When the angular separation between targets is 10° or more, as in figure 115C, no echo is obtained from target 2. It is then possible to get an accurate radar bearing on either target 1 or 2 without interference from the other.

The bearing resolution of a radar can be improved by turning off the lobe switching. This results in a narrower effective beam, but the accuracy of bearing determination is considerably decreased.

3. Reliability of Radar Bearings.

Optical bearings are more accurate and more reliable than radar bearings under all conditions in which it is possible to use the optical system. However, in a night engagement it usually is impossible to use telescopes because either there is insufficient light, or the trainer loses his dark adaptation when the first salvo is fired.

The limitations imposed by lobe switching tend to make unreliable the bearings obtained under some conditions. For example, the trainer may believe that he is on target because his pips are matched, yet the antenna may be directed at a point between two targets within the resolution angle. Proper training of the operators should enable them to recognize such a false indication by observation of the behavior of the echoes.

Many times radar contacts have been reported on bearings where no target can be seen. In rare cases these so-called phantom echoes may be submarine periscopes. Generally, however, phantom echoes are caused by difficulties that can be rationalized into some form of multiple reflection echoes, second trip echoes, reflection from clouds, birds, fish, or side lobe echoes. These will be treated in more detail in chapter VI, since recognizing such contacts is a function of the radar operator. It is important, however, to realize that both range and bearing can be measured on targets that either do not exist at the place indicated, or are targets of no consequence.

C. DETERMINATION OF ALTITUDE BY RADAR

1. Factors That Affect the Accuracy of Altitude Determination.

Since the radar can detect airplanes at long ranges, it can be very useful in directing the interception of attacking planes before they arrive at their target. However, the radar must determine not only the range and bearing of the attacking group, but also

its altitude. For ease in controlling an interception, the radar should be able to indicate the relative altitude of two groups of planes within 1,000 feet if the interception takes place during good visibility, and within about 500 feet at night or in poor visibility. When it is considered that airplanes may be detected as far away as 100 miles and more it is evident that altitude accuracy on the order of 500–1,000 feet requires extremely precise measurement. For example, at 18,000 feet altitude and a range of fifty miles, the position angle of a plane is 3.13°. If the plane changes altitude by 500 feet, the position angle changes only 0.1°. As a result, it is exceedingly difficult to make practical shipboard radar that is capable of measuring altitude to the accuracy desired for control of aircraft that are remote from the ship. However, because the maximum effective range of antiaircraft fire is on the order of 10,000 yards, small errors in determining position angle of airplanes do not result in large errors in altitude. Therefore, the accuracy in angular measurement of which fire control radars are capable does not limit the accuracy of antiaircraft fire.

After a study of the coverage of a radar, it is possible to estimate the altitude of an airplane by noting the range at which it is first detected. It must be realized that because so many factors beyond the control of the radar operator affect the first pickup range, such an estimate is at best a gross approximation. If the radar operator does not notice the echo when the target is first detected, the estimated height will be low. Since propagation conditions may alter as the weather changes, and because the radar can become detuned or out of adjustment, the performance of the set may vary from day to day. If the target is a group of large planes, the estimated altitude will be lower than if the target is a single small plane. Finally, a very serious drawback of attempting to estimate altitude by noting the range of first pickup is that the operator must assume that the plane continues to approach at constant altitude. If the plane takes evasive action—even so simple a maneuver as going into a long glide—the estimated altitude will be worse than useless; it may be fatally misleading. Because of these many serious limitations, estimation of altitude by this method is rarely accurate enough to be used alone. Therefore, altitude data supplied by estimation from the range of first pickup should be used only to supplement other indications of altitude. When echo boxes are made available to the fleet in quantity, the accuracy of this method of altitude determination should become considerably better because it will be possible to make certain that the radar is giving standard performance. This should serve at least to eliminate one variable from this estimate.

Air search radars in general have wide antenna beams in the vertical direction, and the antennas cannot be elevated. Because of these factors, air search radars cannot *measure* altitude or position angle; they can only provide information on which to base an estimate of altitude. The information derived

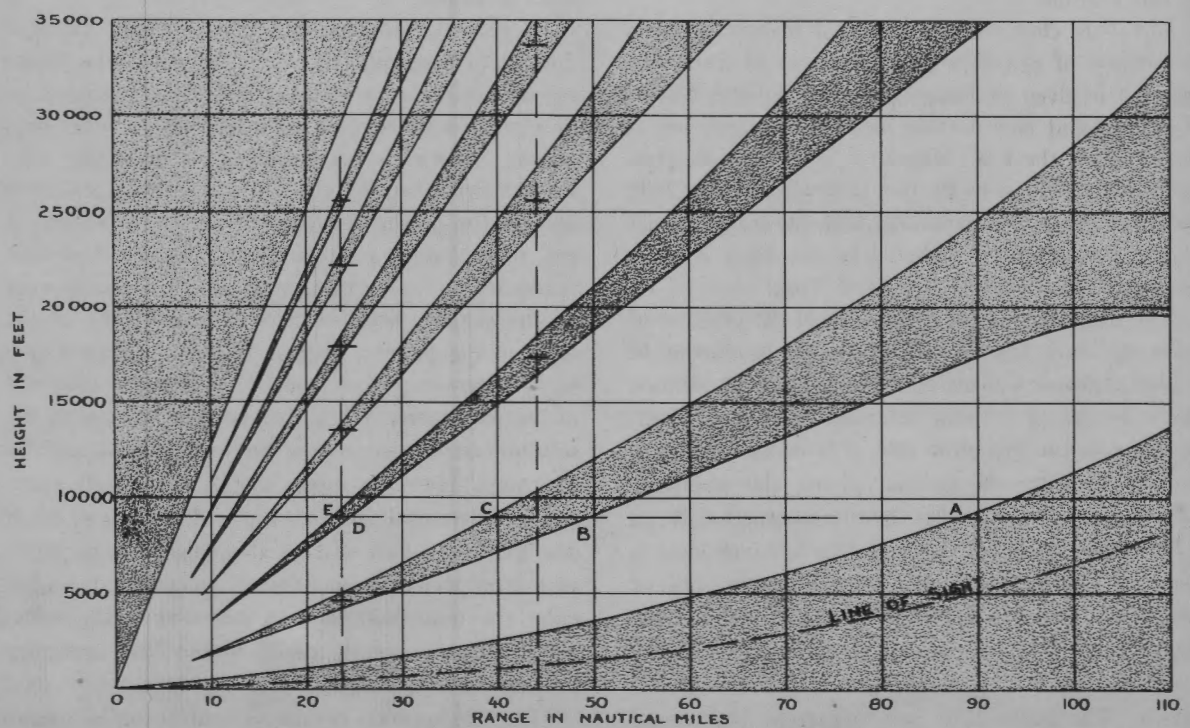


Figure 116—Typical fade chart.

from the radar must be applied to a plot of the vertical coverage pattern of the radar, called a fade chart, to approximate the altitude of an airplane contact.

A typical fade chart constructed for an antenna height of 80 feet and a frequency of 200 megacycles is shown in figure 116. If a plane flies toward the radar at a constant altitude of 9,000 feet, it should be detected near point *A*, 88 miles away. As the plane continues level flight, the echo amplitude increases until it reaches a maximum, and then decreases as the plane approaches *B*. Between *B* and *C* the echo will fade completely.

Observation of the mean range between points *B* and *C*, then, indicates that the plane is at either 9,000, 17,500, 25,500, or 33,500 feet. Correlation of the range of first pickup with the possible nulls shown on the fade chart indicates that the plane is probably at 9,000 feet. As the plane continues in level flight, it will fly through other nulls, so that the altitude can be determined with greater certainty as additional data are observed. Comparison of the mean range of the null between points *D* and *E* with the fade chart shows that a plane would be in a null at 23.5 miles if it was at 4,500, 9,000, 13,500, 18,000, 22,000, or 25,500 feet altitude. Since null *DE* is the second one through which the plane flies, the best altitude estimate is 9,000 feet. It is apparent that the target is not at 25,500 feet, for example, because the null at 23.5 miles would be the fourth null rather than the second, for a plane at this altitude.

The fade chart can be prepared in several ways. A method of calculating the positions of nulls and maxima is given in Radar Technical Bulletin No. 2. A more rapid and flexible method of calculation is described in the CIC Magazine, vol. I, no. 8, published October 1944. By this latter method the fade chart is constructed graphically with the aid of special charts devised and distributed by the Fleet Administrative Office, Navy Yard, New York.

This same method of calculation of the position of lobes and nulls has been applied to the production of a Null Altitude Calculator that allows target altitude to be estimated without reference to a fade chart. In order to use this slide rule, it is necessary first to calculate a factor K by multiplying the frequency of the radar, in megacycles, by the antenna height, in feet. Four scales are provided to accommodate a wide variety of frequencies and antenna heights, of which only two can be put on the device at one time. As an example of the use of the slide rule, take the radar for which the fade chart in figure 116 was drawn. The factor K is 200 megacycles per second $\times$ 80 feet $=$ 16,000, so that the red scale labelled $K = 16{,}000$ must be used. A scale made up for $K = 20{,}000$ is provided in green markings on the same discs. Additional discs are furnished to provide scales for $K = 24{,}000$ and $K = 28{,}000$, but these are not shown in figure 117. The fades in figure 116 occur at ranges of 44, 23.5, 16.3 and 12 miles. To find altitude, the red 1, the index for the outer scale, is set to 44 miles on the range scale. It is then apparent in figure 117 that the altitude indicated on this outer scale at the zero range line (at 9 o'clock) may be 9,400, 17,600, or 25,600 feet. Another point is needed to resolve this ambiguity. The red 2 on the next inner scale is set to 23.5 miles on the range scale, and at the zero range line the altitude shown on the second scale may be either 9,200, 13,200, or 18,000 feet. The ambiguity is still unresolved, because the altitude could be either 9,300 or 18,000 feet. If the red 3 is set to 16.3 miles and the red 4, on the innermost scale set to 12 miles, the best estimate of altitude is 9,200 feet, and the other values may be rejected. This estimate could be verified more quickly by use of the altitude estimated from the range of first detection in addition to the ranges of the nulls.

Although fade charts can be calculated or a null calculator used, altitude can be estimated more accurately if the positions of the lobes and nulls are determined by thorough flight checks. These checks should be as comprehensive as possible in order that indication can be made on the fade chart of the differences that exist in the lobe structure for several types of targets.

In general, the nulls are broad, which makes it difficult to determine the ranges at which the planes are at the minimum points. When the performance of a radar is below par, the nulls will be wider than normal. In a new installation of an SK-2, the nulls are somewhat broader than in a new SK installation because the power delivered to the SK-2 antenna is less than that to the SK. Even though these two radars use the same transmitter, there is a difference in the output, and therefore in the width of the nulls in the pattern, because the SK-2 operates at a higher frequency than the SK where the efficiency of the transmitter is less, and because the loss in the solid-dielectric transmission line of the SK-2 initially is greater. However, unless the SK is carefully maintained, its transmission line loss will increase so much that the two radars will be about equal in performance after about six months of operation. In either radar the nulls will be very extensive if the transmitter is not carefully tuned to the best operating frequency of the antenna.

Thus, the accuracy of altitude estimation by means of a fade chart is dependent not only on the skill of

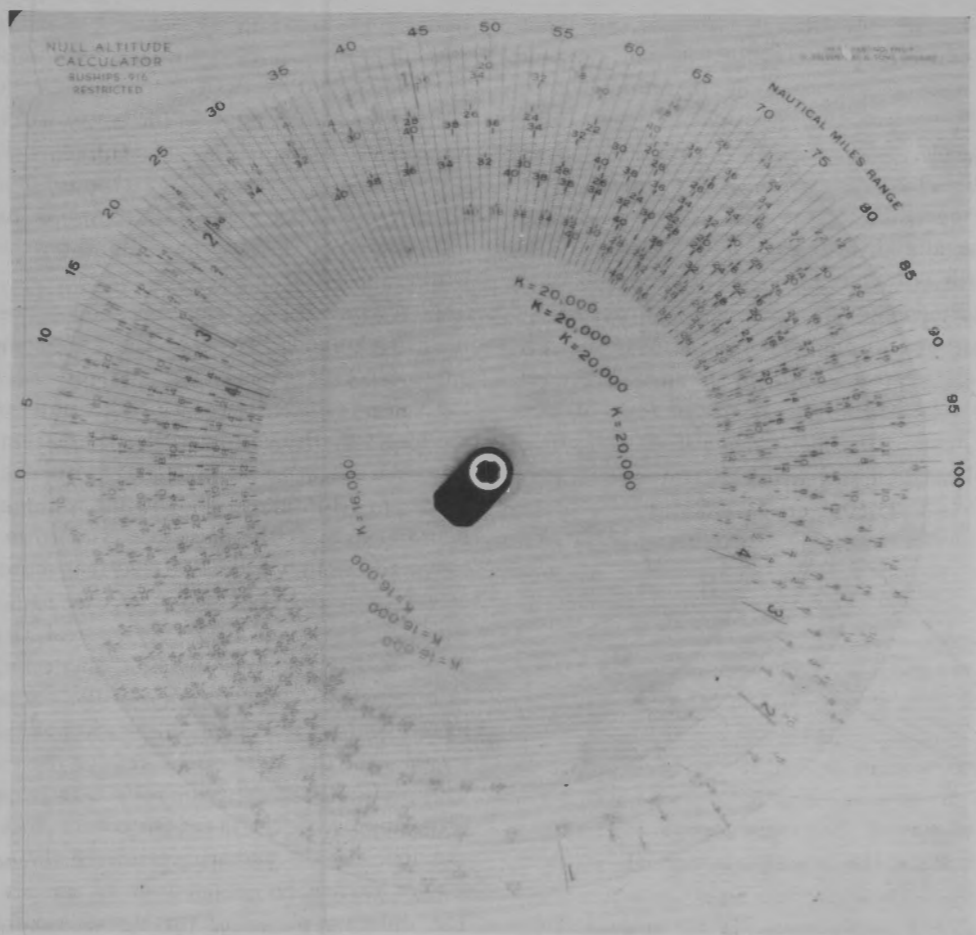


Figure 117—Null Altitude Calculator

the operator in obtaining the range of the null and on the care with which the chart is constructed, but also on the level of performance of the radar set. If the plane is flying at constant altitude, its height can be estimated within 1,500 to 2,000 feet by use of the fade chart. This accuracy is not a function of the range of the target except insofar as the plane must fly several miles to pass through two nulls. If the plane continues at constant altitude, the height can be determined more precisely the nearer the plane approaches simply because it flies through more nulls. But if the plane changes elevation, the estimated altitude will be error an amount dependent on how radical the change of altitude is.

On aircraft carriers, some of the radiated energy may be reflected from the flight deck rather than from the water on some antenna bearings. The lobe pattern will be altered if this happens because the effective antenna height will be decreased to the elevation above the flight deck, rather than above the water. On such bearings the apparent altitude will be higher than the true altitude because the lobes and nulls are pushed up by the lower effective antenna height. Although this error will be present over only a limited arc, the possibility of its existence should be investigated by flight tests.

Nonstandard propagation or trapping conditions have some effect on height finding accuracy, but usually at low altitude only. The principal effect of trapping is to preclude the use of the first detection range as a basis for estimating altitude. Since excessive bending of the radiated rays occurs only at angles less than 1°, the pattern at higher angles is relatively unaffected by weather conditions. Thus neither failure to track a high-flying airplane, nor grossly inaccurate estimation of its altitude by reference to a fade chart can be blamed on the weather. Rather, such failure should result in an immediate overhaul of the set to discover why its performance decreased.

Altitude cannot be *measured* directly by radar, but the position angle and range of airborne targets can be determined, and from them the altitude may be computed. Position angle can be measured only by radars whose antennas can be elevated. Altitude is calculated using position angle and range on the assumption that the earth is flat. Since the earth is round, this assumption causes the resultant altitude to be low by an amount that varies with range. At a

range of 50 miles, the calculated altitude may be as much as 1,600 feet low. However, at long range it usually is desired to know only the difference in altitude between two groups of planes, so that the error caused by assuming the earth to be flat cancels out. At the short ranges where AA fire is practicable, the curvature of the earth causes negligible error in the altitude determination. Thus, the fact that the earth is round should not cause appreciable error in most operational measurements of altitude.

Lobe switching is often used as a means of measuring angles more precisely than maximizing the echo on a single lobe will allow. A special form of lobe switching, called conical scanning, is convenient to employ when it is desired to measure both bearing and position angle. In this type of scanning the axis of the antenna lobe is slightly displaced from the optical axis of the reflector, and caused to rotate about this axis. As indicated in figure 118, the tip of the beam traces a circle in space.

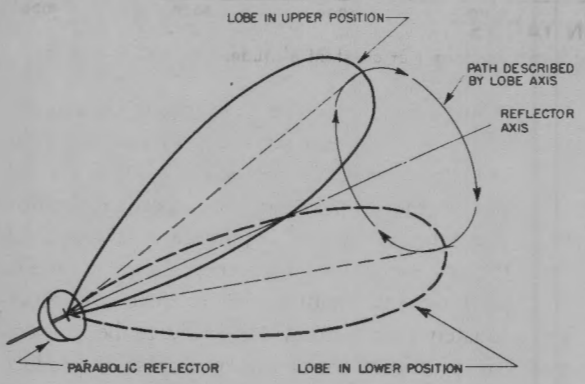


Figure 118—Conical scanning.

With lobe switching and conical scanning the echoes are so displayed that the operator has an indication of the direction to move the antenna to get on target. In general the echoes from the left and right positions of the lobe are supplied to the trainer's indicator while those from the up and down positions appear on the pointer's scope. The indication may take the form of two pips side by side, or of a moving spot such as that shown in figure 16.

Position angle can be more accurately determined the narrower the radar beam is in the vertical direction. Practical considerations at present limit accuracy of search radars that use lobe switching to approximately 1/3° to 1/2°. To exceed this value, either the antenna must be made excessively large or an extremely short wavelength must be used. In general, the accuracy with which position angle can be determined is affected by the same factors that enter into bearing determination since the methods used are the same.

In systems that use lobe switching or conical scanning, inaccurate pointing develops when the position angle is small enough for some of the energy in the radar beam to reach the target and return from the target by the indirect path of reflection from the water's surface. The path taken by this reflected energy in returning to the antenna is along *TWA* in figure 119. Since the pulses are assumed to follow an essentially straigh path, the echo that returns by way of reflection from the water appears to be returned from *T'*, a virtual image of the real target at *T*. Thus, at low position angles, a single target seems to become two targets because of the presence of the image, and measurement of position angle becomes erratic since the radar cannot resolve the two targets. This difficulty arises principally because as an airplane approaches the radar, the echoes returned to the two lobes of the antenna experience the same interference that is encountered in an air search radar. The differing phases of the signals returned in the two lobes cause the pips to be matched on the radar for positions both above and below the true position of the target. If the pips are matched constantly, the antenna axis will oscillate up and down between directions above and below the target, being pointed low a large percentage of the time. The apparent track of a plane flying at constant altitude would then resemble the curve shown in figure 120, which shows the general way in which radar pointing errors change as the target approaches.

Below position angles of 30 minutes the pointing errors are quite small since the angle between the target and its image is so small that both the lobes are affected almost equally by the direct and reflected rays. As the position angle increases, the pointing errors also increase. At times, these errors may reach magnitudes of several degrees for targets between

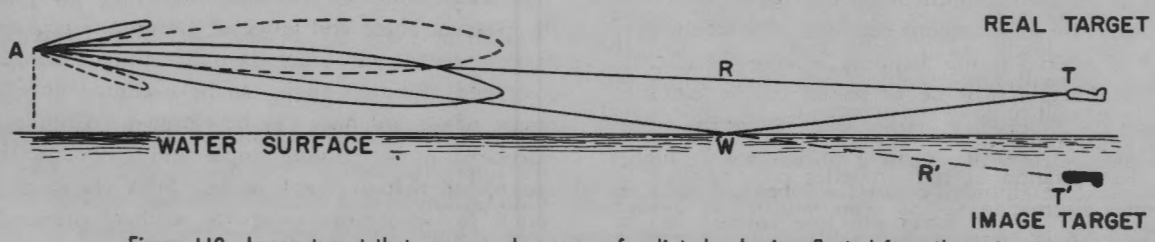


Figure 119—Image target that appears when some of radiated pulse is reflected from the water.

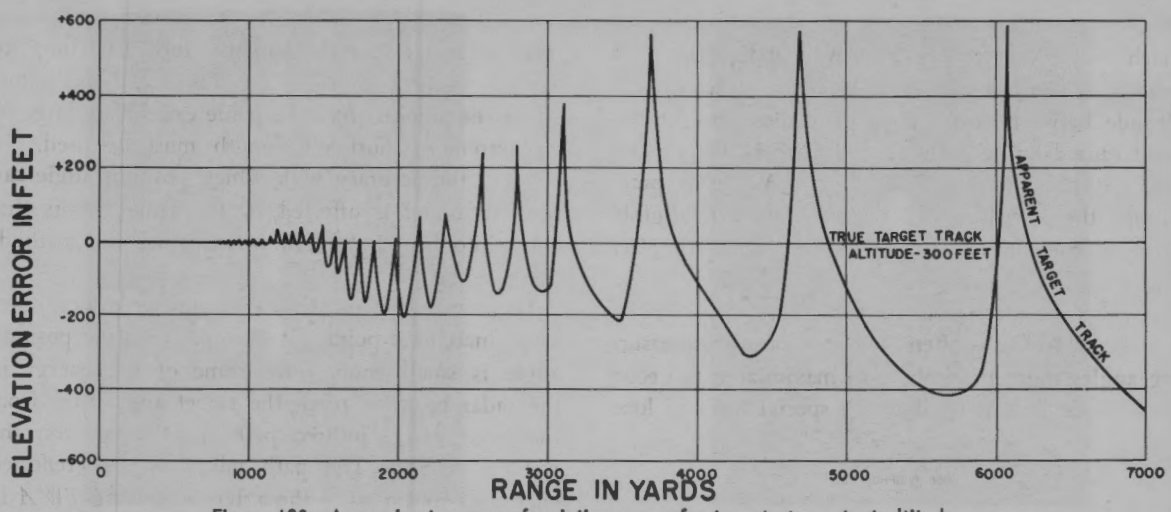


Figure 120—Approximate curve of pointing errors for target at constant altitude.

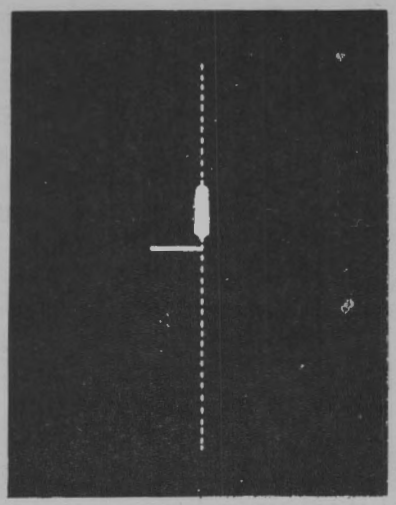
position angles of 1/2° and 10° for radars such as the Mark 4 or Mark 12.

The minimum position angle at which accurate height-finding is possible is determined by the position of the antenna in which none of the energy reflected from the target can return by way of reflection from the water. This angle is approximately equal to half the vertical beam width of the antenna. Thus, the narrower the vertical beam width, the lower will be the altitude at which the radar can measure position angle accurately. Since lobe switching or conical scanning makes the effective beam angle greater, the lower limit of unambiguous height finding may be extended by turning off the lobe switching mechanism. Position angle would then have to be determined by maximizing the echo on the single lobe.

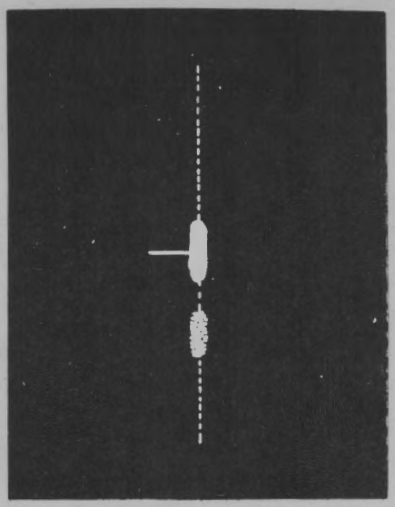
Although this step may be useful in some conditions, it must be realized that the angle cannot be determined as precisely with the single beam as with lobe switching. Since the nature of the lobe switching mechanism causes the lobe axis always to be off the antenna axis, the position in which the lobe stops is not known. Therefore, the position angle measured with the single lobe may contain a rather large constant error. When the single lobe is depressed sufficiently to allow some of the energy to strike the water, the beam will be broken up by interference into nulls and lobes like those shown in figure 11 or figure 116. As a low-flying plane moves toward the radar, then, it will fly rather quickly through closely-spaced nulls and lobes, and the echo size will vary rapidly. Under these conditions it is difficult to point the antenna to the position that gives maximum signal.

The rotation of the propeller on airplanes also causes fluctuation in the echo returned to a radar. The echo is greatest when a blade of the propeller is horizontal, and somewhat less when the blade is vertical. This effect causes a cyclic variation in echo height of approximately 15 per cent. If the number of blades on the propeller and the speed of rotation cause the echo to vary in amplitude at a frequency near the lobe-switching frequency, large errors in both pointing and training the antenna will occur. Unfortunately, such errors are likely to be encountered in practice because many airplanes produce propeller modulation frequencies near 60 or 90 cycles per second, which cause trouble in lobe switching or conical scanning equipment that is operated from a 60-cycle power source. These errors may be reduced to a negligible value if the lobing frequency can be made four or five cycles different from the propeller modulation frequency.

Because of the position angle inaccuracies inherent in radars Mark 4 and Mark 12 for targets at low altitude, an auxiliary radar capable of accurate measurement of small position angles has been produced. This radar, which is designated Mark 22, is operated on the X band so that a narrow beam can be produced with an antenna of reasonable size. The antenna beam, which is approximately 1.2° wide in the vertical direction, is swept up and down over an arc of 12°. When the beam is pointed directly at the target, one echo is received; when the antenna is pointed at the image of the target, another echo is received. These echoes are displayed on a special indicator which shows echoes from only the range selected by the radar to which the Mark 22 is connected. At position angles greater than 3°, only one bright line appears on the indicator, but at lower angles, both the real and image echoes may be seen, the upper line being the real echo (fig. 121B). At position angles less than 1°, the two echoes merge into a single bright line, but the operator can still



A. Mk 22 beam pointed below target. Target is above position angle of 1.5°.



B. Mk 22 beam pointed correctly at target. Note water image of target because of low position angle.

Figure 121—Mark 22 radar indicator.

distinguish between the two parts of the echo down to approximately 0.6°. Within the range of use, an operator can measure position angle within approximately 3 mils. Below 0.6°, the error of measurement is increased as the effect of water reflection begins to become pronounced.

The principle of finding position angle by means of a very narrow beam that is fanned vertically is used in the SX radar, and it may be introduced into the SP as a modification. This type of scanning permits presentation of echo pips on a Range-Height Indicator (RHI), such as that shown in figure 122, on which is displayed not only the ranges of all targets along a particular bearing, but also the height of each target. This type of indicator is a section of a sort of PPI, but instead of showing a plan view of an area, it shows a cross section of the atmosphere. For convenience, the scope is designed to show altitude in feet, corrected for the curvature of the earth, rather than position angle. The advantages of the fanning beam and the associated RHI scope are the thorough coverage provided, the instantaneous, continuous indication of altitude of all targets that are within the region covered by the beam, and the high degree of accuracy possible with the very narrow antenna beams used in this system.

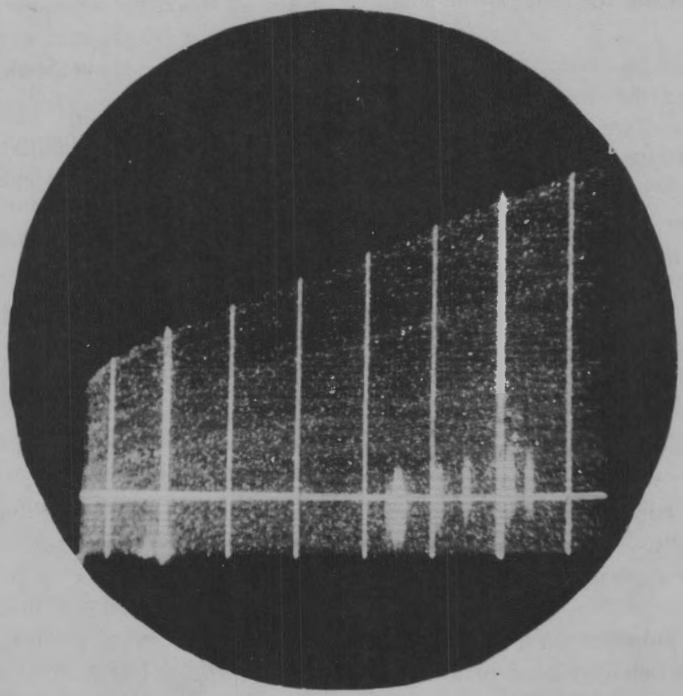


Figure 122—Range-Height indicator.

In the SM and SP radars the height of aircraft is indicated on a meter which automatically solves a right triangle using position angle and slant range data. If the voltage supplied to the equipment is perfectly constant, the current through the meter is controlled only by the mechanism that solves the triangle, and the indicated altitude is correct. However, if the supply voltage varies, it may cause the current through the meter to change independently of the computer. As a result, the altitude indicated on the meter may vary 1,000 feet or more for a plane in level flight. In many ships the position angle and position angle cannot be measured more accurately than within 1/2° of the true value, the actual position angle of the plane may be between 3.5° and 4.5°, even though the radar indicates 4°. As a result, the indicated altitude at a range of 20 miles is 8,400 feet, but the plane may be at any altitude between 7,350 feet and 9,450 feet. When the range increases, the altitude error also increases. Thus at 50 miles the plane may be between 18,400 feet and 23,600 feet when the indicator shows an altitude of 21,000 feet. At 80 miles, the actual altitude is within 4,200 feet above or below the indicated value of 33,500

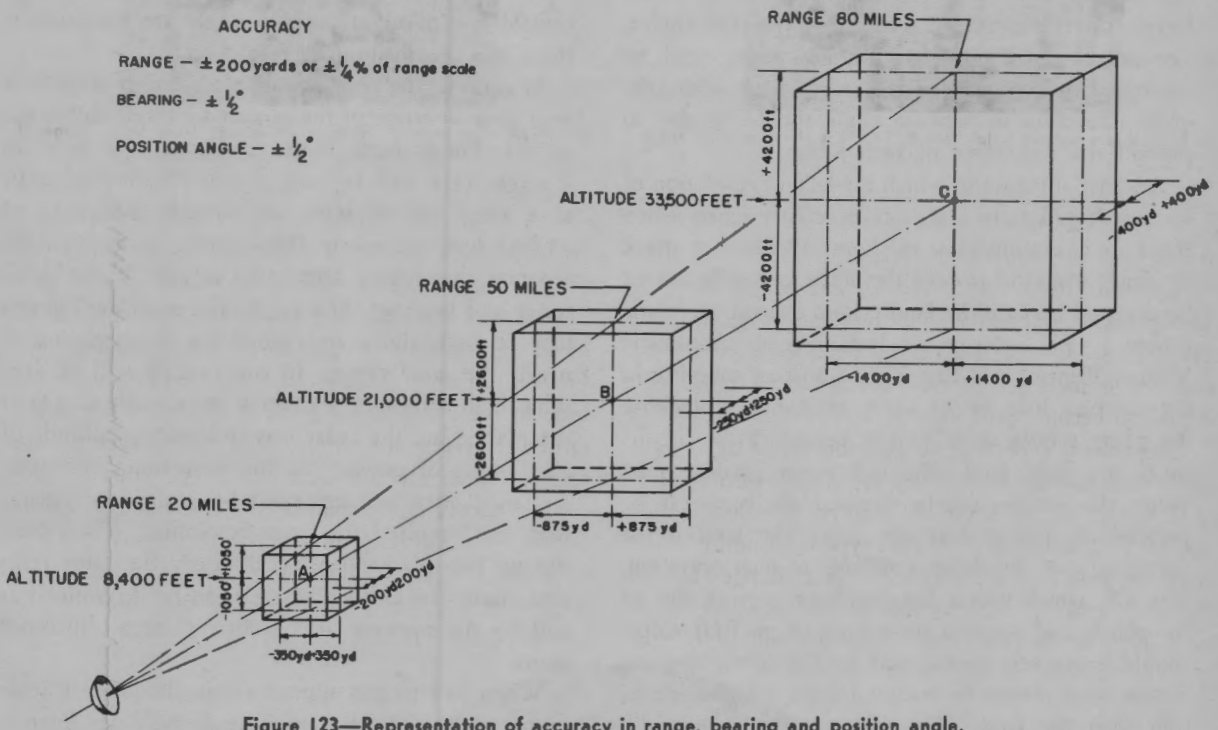


Figure 123—Representation of accuracy in range, bearing and position angle.

range are read off the dials on the indicator and applied to a graph to solve for altitude. This method is somewhat slower than the direct use of the meter, but the greater consistency of the results warrants the slight delay entailed.

The accuracy of finding height of airplanes by measurement of position angle is proportional to the range, since a small angular error subtends a greater altitude as the range increases. In figure 123 is shown a representation of the errors of the SM radar. The range of a target can be determined within ±200 yards or ±¼% of the range scale, whichever is the larger, and both bearing and position angle can be determined within ±½°. A target at a range of 20 miles and an altitude of 8,400 feet is shown by the radar to be at point *A*. If the target remains at the same position angle, but moves to a range of 50 miles, the radar will indicate that it is at point *B*, and at a range of 80 miles, at point *C*. Since the feet. Since neither range nor bearing can be determined without error, similar limits of the possible position of the target also exist in these dimensions.

The fact that errors exist in the data obtained by radar prevents the determination of a *point* at which the target is. Instead, the radar can indicate only the volume of space that contains the airplane, and the size of this volume increases with the range. This factor is a serious limitation on the control of airplanes from shipboard, since it is desirable to intercept attacking planes at a point 50 miles or more away. At this range, a radar having the accuracy specified in figure 123 is not capable of indicating precisely the position of either attacking or defending planes.

2. Factors That Affect Resolution in Altitude.

If the radar antenna cannot be tilted, the radar cannot resolve between two targets that are at different altitudes but at the same range and bearing. There-

fore, it is not possible to detect an airplane over a ship except when either the range or bearing difference is enough to produce separate echoes. In general, this may not often be a handicap because the plane moves so much more quickly than a ship that the two targets cannot stay at the same range for long. However, in a recent action a snooper plane escaped fighters by running through AA fire into cloud cover over a formation of ships. For more than an hour the snooper was able to scout the formation without being detected, because the many echoes from nearby ships masked the echo from the snooper, and because none of the search radars could detect targets directly overhead or at high position angles. The snooper did not show on any radar until he attempted to get away. The use of radars with adequate resolution in position angle should be able to prevent the recurrence of such action.

Another situation in which the lack of resolution of air search radars is a serious deficiency exists when ships are operating close to shore. Planes that attack by flying overland toward the ships generally cannot be detected because the land echoes conceal the plane echoes. The inclusion of Instantaneous Automatic Volume Control and Fast Time Constant coupling in the receiver may be of some assistance in making the plane echoes more visible, because these circuits break the solid land echo into many small echoes. When the antenna can be elevated, the beam can be pointed so that it does not strike the land if the topography of the shore is suitable to such operation. The SX, which uses a fanning beam to scan the air for planes and displays the echoes on an RHI scope, should prove very useful near land since the airplane echoes must always be returned from a higher elevation than the land. The very narrow beam width used in this radar will show targets that are only a small angle above the land. The Mark 22 radar will also be useful for the same purpose, but to a less extent because echoes from only a particular range can show on the indicator. A modification of the Mark 22 radar, which will be the Mark 22 Mod 1, will be of greater utility in searching over land for aircraft because echoes will be displayed on a type E scope. In this indicator the vertical dimension of the screen represents position angle and the horizontal dimension shows range, but only 2,500 yards will be visible on the screen at one time.

In spite of their lack of altitude resolution, air search radars are very useful in helping to control interceptions. When two groups of planes are at distinctly different ranges, it is possible to estimate the altitude of each by reference to a fade chart. Control can be exercised until the two groups approach within the range resolution distance. At this point either the visibility must be good enough to allow the intercepting fighter pilots to make visual contact, or interception radar must be furnished so that they can make radar contact on the enemy. A serious handicap in such an operation is the inability of the air search radar to indicate altitude continuously, and to indicate difference in altitude at the time when the fighters close on the attacking planes.

For radars that have antennas which can be elevated, two targets at the same range and bearing will produce two distinct pips only when the targets are separated in position angle by more than half of the effective vertical beam width. The factors which control resolution in position angle are the same as those that control bearing resolution.

In general, the position angle resolution possible is very poor in terms of the required altitude difference in feet. For example, if the resolution angle is 3°, as it might very well be with a conical-scanning radar, at a range of 50 miles an altitude difference of 15,000 feet, or nearly three miles, is required to separate the echoes from two targets at the same range and bearing. In a large raid, escorting fighters may be both above and below the bombers, but at nearly the same range. In this case, it will be very difficult to determine accurately the altitude of any of the planes, but the radar may indicate the altitude of the "center of gravity" of the formation. However, airplanes often are separated by a distance greater than that required for range resolution. Thus, even though two planes may be at nearly the same position angle, the altitude of each can be determined at will by the operator if a sufficient range difference exists.

When two targets appear within the altitude resolution angle, either the pointing of the radar antenna will be erratic, or an on-target indication will be obtained on a point between the targets. For example, when a plane is circling only a few thousand feet above a ship, the antenna will point well below the plane. Accurate pointing at the plane is difficult because the strong echo from the ship increases the position angle difference required for resolution.

3. Reliability of Altitude Determination.

Whenever it is possible to see the target, optical pointing is much more accurate and reliable than radar pointing. Radar pointing is reliable only at position angles great enough that none of the radiated energy strikes the water. For example, with radars such as the Mark 4 or Mark 12, even a target as high as 8,000 feet at a range of 20,000 yards will have an image below the surface of the water, making accurate determination of altitude difficult. The addition of the Mark 22 radar to these equipments

will provide reliable altitude data on all targets within the range of antiaircraft fire.

The altitude estimated by noting the range at which the target is first detected is far from reliable. Such data should be regarded merely as a guess, because reduced radar performance or evasive action by the target can make this information very misleading.

If an attacking plane approaches in a long glide, it may be impossible to get any reliable indication of altitude. For example, if the fade chart of the air search radar is similar to that shown in figure 116, a plane could glide from an altitude of 15,000 feet at a range of 100 miles to less than 1,000 feet at 10 miles without crossing any nulls. The target could produce a plainly visible echo during the whole approach, but the only estimate that could be made of altitude would have to be based on the first pickup range. Possibly the attacking plane could fly down a null of the coverage pattern, but deliberate flying of this sort would require very careful management of the plane as well as special equipment to keep the plane in the zone of minimum signal. Experiments with tactics of this sort indicate that it is not practical to avoid radar detection by flying in a null, although there are indications that the Japanese have both the equipment and the knowledge necessary for the adoption of such tactics. A long gliding approach will defeat the height finding methods employed with air search radar, so that planes employing this kind of evasion may avoid interception. The Japanese are apparently well aware of this limitation on the reliability of altitude determination.

Another maneuver that takes advantage of the limitations of air search radar is for the attacking planes to approach at low altitude to avoid detection as long as possible, and to climb sharply when they reach the range at which detection is likely. In one engagement Jap planes were detected by the SK at a range which indicated that they were at an altitude of approximately 2,000 feet. Fighter planes were vectored out to intercept at this altitude, and the pips were seen to merge, but no tally-ho was reported because the attacking planes began to climb at about the time that they were reported. When the pips merged, the two groups of planes were several thousand feet apart. The attacking planes were later detected visually at 18,000 feet in a position suitable to begin attack.

When a plane wishes to withdraw from an action, and to avoid being followed by radar, it can dive sharply to a low altitude and retire close to the water. At low altitude the echo disappears, and because the air search radar cannot detect changes of altitude, this maneuver can rarely be detected while it is in progress.

It is difficult to establish on a PPI scope the ranges at which the echo fades completely because of the rotation of the antenna. For example, if an SK antenna is rotating at two revolutions per minute, an airplane can be detected for less than two seconds out of each 30 seconds required for the antenna to

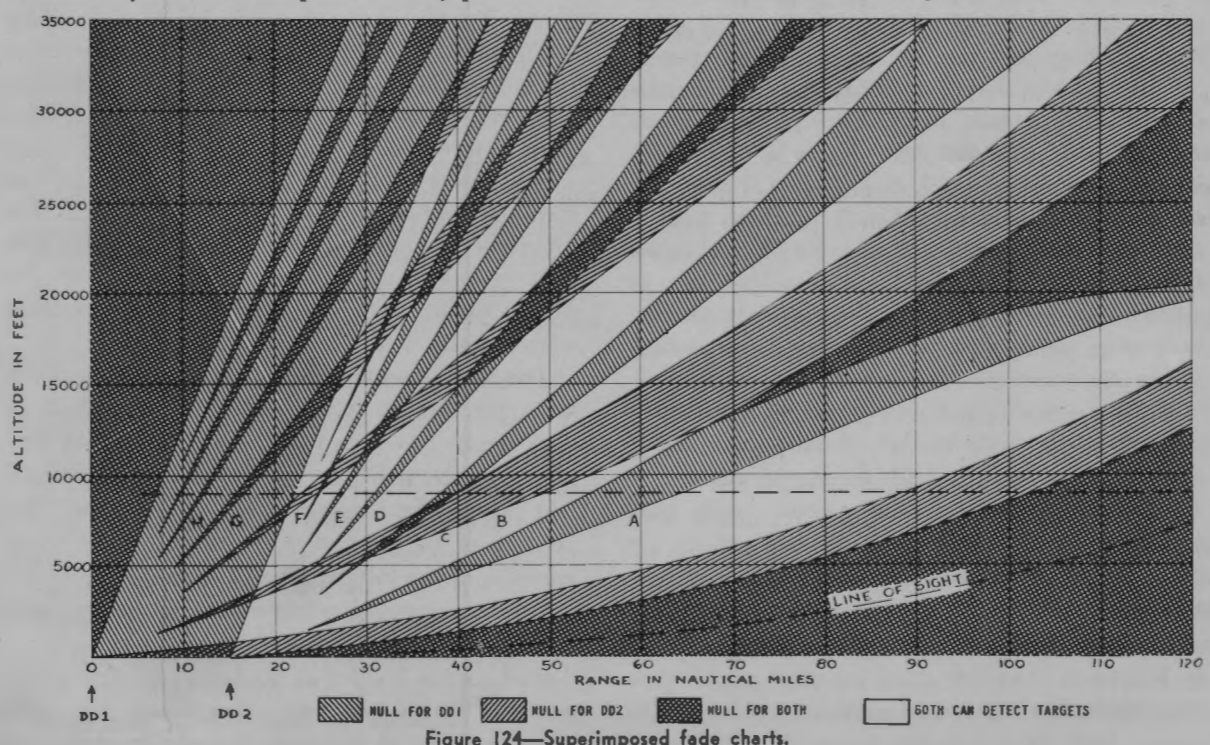


Figure 124—Superimposed fade charts.

scan 360°. A 250-knot airplane can fly 2 miles in the 28-second interval during which the echo is not visible. As a result, the plane could pass all the way through a narrow null area while the antenna was turned away, and the fade therefore would not be observed. If the null area is wide, the intermittent observation of the echo makes it difficult to estimate altitude by the use of a fade chart when the ranges of the nulls must be read from the PPI scope. Since the antenna must rotate continuously to maintain an effective all-around search, reliability of altitude determination must be sacrificed to some extent to provide security against attack from an unguarded direction.

The reliability of altitude determination will be greater the more frequently ranges on the fade zones can be obtained. Generally only three or four nulls can be observed with a single P-band radar, so that insufficient data are available to permit making a dependable estimate of height. However, when several ships are in company, the ships of the screen can be so placed relative to the center of the formation that the nulls of one radar are illuminated by the lobes in the coverage pattern of another. Such an arrangement would not only force attacking planes to fly through nulls that are conveniently staggered, but also would result in a more secure search. For example, a composite fade chart for two destroyers 15 miles apart is shown in figure 124. It is assumed that the antenna height is 80 feet and the frequency 200 megacycles on both ships, so that this illustration shows simply the fade chart of figure 116 plotted twice on the same page. In the white areas, both radars can detect targets; in the areas shaded by single cross hatching only one set can get echoes, but in the dark areas of double cross hatching neither radar can detect any targets. If the enemy planes approach at an altitude of 9,000 feet, they will fly through nulls at points *A, B, C, D, E, F, G,* and *H* (compare fig. 116). If the range of each of these nulls is reported on the Inter-Fighter Director Channel or the Radar Reporting Net, both ships will be able to arrive at an altitude estimate more quickly than by each using only her own data. The estimated altitude will be more reliable because more data are obtainable.

In some operations, it may be useful to construct composite fade charts so that all information available may be used to help determine altitude of approaching planes while they are still remote from the formation. If more than two fade charts are superimposed, the resultant plot may be too confusing to use unless color is employed.

At ranges beyond 50 miles, altitudes determined by estimation from fade charts are more reliable than those determined by conical scanning radars. This is caused both by the limitation on the accuracy of measuring position angle, and by the fact that at long range the position angle of most targets will be so small that large errors will be caused by water reflection. Although the altitude indicated by an SP radar may be correct within only 3,000 feet at long range, the fact that a nearly continuous indication of altitude is possible enables any maneuvers of the target to be detected. The conical scanning feature gives the radar operator a sense of direction, so that he knows which way to move the antenna when the targets maneuver.

The altitude accuracy possible with a conical scanning or lobe switching radar is increased as the vertical beam is made narrower. Very narrow beams, then, enable the radar to measure altitude very reliably, *once the beam is on the target.* However, it is rather difficult to find a target with a narrow beam, particularly if the altitude is not known. For example, in one evasive maneuver previously mentioned, Japanese planes approached low and then climbed quickly. The SM radar should have detected this change in altitude, but it was misled by the initial altitude derived from the air search radar. Consequently the SM had to search in altitude with its narrow beam, and the attacking planes were close in by the time they were found. The antenna of any lobe switching or conical scanning radar must be stopped on the target for some time to allow position angle to be measured. Therefore, when an interception is in progress, the SM or SP radar cannot be used for all-around searching if dependable altitudes are to be obtained, and these sets, then, are *not* fighter direction radars, but only height-finding sets. When the target has a high rate of change of position angle, it is difficult for lobe switching radars to keep on target, especially if the pointer must match pips. Thus, a dive bomber can be followed by radar only with difficulty, if at all. Any altitude indication on such high-speed targets is likely to be unreliable. The SX, however, should provide a remedy for this difficulty in its fanning beam and RHI presentation, but this set has the tremendous drawback that its antenna weighs nearly 4 tons.

The Mark 22 antenna is scanned vertically at two scans per second. Consequently, it is difficult to track targets that have a high rate of change of position angle because the bright line on the indicator lags behind the actual position of the plane. The position of the spot, then, is not a reliable representation of the true position of a diving airplane.

Presently available radars do not, in general, provide good, reliable altitude data to the accuracy desired for the control of airplanes. Therefore it is necessary to get data from all available sources in order to arrive at the most dependable estimate of

the altitude of the target. New radars are being developed to meet the problem of altitude determination, but they will not be available before the latter part of 1945.

D. MATERIEL FACTORS

1. Training of Maintenance Personnel.

Most radar materiel schools attempt to teach the fundamental principles on which all radars operate. Several of the more commonly used radar equipments are employed as vehicles for this instruction. As a result of this type of instruction, it is sometimes found that maintenance personnel do not have a complete knowledge of all the details of every radar set that they encounter on board ship. This unfortunate state of affairs is forced to exist because there are so many different types of radar that it is impossible to teach them all thoroughly to every man within the time allowed, and because the exact nature of each man's assignment is seldom known before he is graduated from school. In any case, it would be undesirable to train each man on only the equipment that he will encounter immediately, because such training would result in excessively narrow specialization. Rather, the training philosophy is directed toward instilling a thorough comprehension of basic radar principles in order that any radar system can be understood after relatively brief study of the manufacturer's instruction book. Since most of the mainland schools cannot offer specific training that will suit every need, a reasonable time must be spent in familiarization and orientation. As a result, the maintenance personnel that come direct from schools in general are not fully effective during their first month or two. After they become well acquainted with the equipment, the background provided by the materiel schools should enable them to maintain all the radars in good condition.

However, maintenance of radar in a state of high efficiency is not a matter of training alone. The maintenance personnel must become experienced and they often must be very resourceful to keep the equipment operative. A few suggestions that should aid in developing an effective maintenance crew are contained in the following extract from a letter from the Chief of the Bureau of Ships:

> "4. The Bureau is of the opinion that proper maintenance of radar is essentially dependent on the Commanding Officer's appreciation of the importance of radar maintenance and on the inherent ability and capabilities of radar maintenance personnel on board.
>
> 5. As a guide to those Commanding Officers who are not thoroughly acquainted with the tremendous problems involved in keeping radar properly operative, the following suggestions are offered:
>
> 1. To place radar maintenance men in the ship's organization that they may give maximum time to knowing and maintaining their equipments. Split duties and responsibilities will inevitably result in poor performance.
>
> 2. Weed out maintenance personnel who are obviously unfit or uninterested.
>
> 3. Make radar technical publications and bulletins readily available to personnel.
>
> 4. Encourage the use and study of radar instruction books.
>
> 5. Make full use of radar manufacturers' engineering services available at most yards and bases.
>
> 6. Encourage initiative in tackling maintenance problems.
>
> 7. Give maintenance personnel every opportunity to attend schools and refresher courses."

2. Preventive Maintenance.

Preventive maintenance includes periodic lubrication, cleaning, inspection, and adjustment of equipment. Simply, it is a systematic application of the old adage, "A stitch in time saves nine." The establishment of a definite maintenance routine that is faithfully carried out will insure maximum reliability of the radar equipment.

The data on all parts that require lubrication are given in the manufacturer's instruction book. Both the frequency of lubrication and the kind of lubricant to use are specified. Periodic lubrication of the type indicated should almost completely eliminate failure of any rotating machinery or bearings in the radar equipment.

Radar equipment involves the use of very high voltages in some parts of the circuit. Arc-over can be avoided if the insulation strength of all insulators is kept high by frequent dusting. Dust, paint chips, and other foreign matter that may accumulate between points where high voltage exists may cause failure of some component, or an outage of the whole radar at a critical time as the result of an arc-over. To avoid such trouble, the equipment should be inspected carefully and often, and the dust blown out with an air hose at regular intervals.

Experience has shown that nearly 80 per cent of the failures that occur in radar equipment are caused by tube failure. In newer radar equipments, the critical tubes in a unit are indicated directly on the set by green bands painted around their sockets. In addition, spare tubes for these sockets are mounted in racks within the unit as a means of helping to keep the set in operation. Since enough data have been accumulated on the average expected life of

most of the tubes used in radar, it is possible to predict approximately when a particular tube is likely to fail. These data are compiled and listed in the Radar Maintenance Bulletin, and in addition a cross index of tube types is shown so that spares for one system can be made available to another in an emergency. Part of the preventive maintenance schedule should include a log of the number of operating hours on each tube so that it can be replaced *before it fails*. Intelligent administration of this sort of program will reduce equipment failures to a very small amount.

In combat, there is no possibility of a technician getting inside a director to repair radar that may fail. Thus, if the radar becomes inoperative because of tube failure during action, it will be useless unless adequate repairs can be made. To increase the reliability of fire control radar, then, the radar operators in the director should be trained to recognize all of the symptoms of trouble caused by vacuum tube failure, and to make the tube replacements in the dark. In order for such a program to be effective, adequately tested spare tubes must be made available to the operator in the director.

Spare vacuum tubes sometimes will not operate satisfactorily in the radar for which they are provided. Another part of the preventive maintenance program, then, should be the testing of all spare tubes in the sockets where they are to be used. This test should involve operating the tubes for a period of perhaps fifty hours. During the test the chassis should be bumped by hand to help eliminate the tubes that will fail because of shock or vibration. Satisfactory tubes should be labelled "Equipment-Tested Spare," and others discarded as provided for in the Radar Maintenance Bulletin.

3. Reliability of Radar Equipment.

Radar is complex precision equipment. As such, it cannot reasonably be expected to operate without failure for long periods of time. Failures in both tubes and other circuit elements are bound to occur in normal operation, especially in the severe conditions encountered on board ship. Failure at critical times can be minimized by an adequate preventive maintenance program. Without such periodic care, the radar may become inoperative at the time when it is most urgently needed.

The life of the components used in electronic equipment is in general limited. Although better parts are constantly being developed, the equipment cannot be operated 24 hours a day indefinitely. In the ideal, all parts that have reached the end of their expected useful life would be replaced before they fail during regularly scheduled maintenance periods.

It has been found that vacuum tubes will operate satisfactorily over longer periods of time if the filaments are continuously heated. Turning on equipment from a cold start causes great stress on the tubes. If this stress is repeated by switching the equipment off and on frequently, the tube life will be seriously decreased. For maximum reliability of the equipment, it is preferable to maintain the radar in a stand-by condition rather than fully deenergized, while it is not required operationally. This type of operation also has the advantage of keeping the humidity low within the unit and of reducing absorption of moisture by the circuit components.

The glass vacuum tubes and porcelain insulators in a radar set may be broken by the severe shock of gunfire. Improperly supported electrical connections or wiring may be broken by the great vibration produced at high speeds or continuous gunfire. All radar equipment is mounted in special shock mounts to avoid these difficulties as much as possible and care is taken in design to insure that all parts have adequate mechanical strength. However, prolonged firing of heavy salvos, as in shore bombardment, may cause failure of some weak parts in the radar in spite of the shock mounting. In general, continuous fire imposes less severe conditions because the shock is less violent than with salvo fire. The effect of the shock produced by gunfire can be accentuated if some components are inadvisedly installed. For example, a component mounted on an outboard bulkhead of a ship is more likely to fail because of shock than one which is installed inboard where the blast of gunfire is less likely to deform the bulkheads.

Fluctuation of the supply voltage often has serious effects on the reliability of radar. If the voltage rises too high, many components may be burned out. Variation in the supply voltage affects the accuracy of some radars, but in many installations the input voltage is stabilized and the voltages provided to critical circuits are regulated electronically. However, where voltage fluctuations do occur, some of the following results may be found, reducing the effectiveness of the equipment or making it inoperative:

(*a*) Decentering of indicator pattern, making the scope unreadable for several seconds.

(*b*) Range inaccuracies.

(*c*) Periodic blanking of the indicator screen.

(*d*) Detuning of receiver.

(*e*) Blowing of fuses or opening of overload relay.

(*f*) Burning out of some circuit elements.

The reliability of radar equipment is affected considerably by humidity, dust, and high temperature. In a humid atmosphere, the moisture that collects on the various elements of a radar circuit may cause corrosion of metal parts or deterioration of insulation. The decreased insulation strength of a damp insula-

tor is further lessened in a dusty atmosphere because of the affinity of the moist surface for dust. Voltage breakdown is very likely to occur if high-voltage insulators are allowed to remain damp and dirty.

Condensation of moisture can be prevented if the temperature of the circuit elements can be held above the air temperature. In normal operation, the heat generated within the radar is very effective in this regard. However, when the set is turned off, the components cool, which may cause them to absorb moisture in a humid atmosphere. Heaters are provided in many sets to prevent the radar from cooling to a temperature below the ambient so that this will not happen. If the temperature of the radar is allowed to exceed 100° F., the life of the vacuum tubes will be shortened and other circuit elements may fail. The radar will be more reliable, then, if adequate ventilation is provided to keep the temperature of the radar transmitter room below 100° F.

False echoes can be produced in some radar equipment by faults that cause spurious oscillations to be excited in some part of the circuit. In general, these false echoes exist at a constant range and appear equally at all bearings. For example, it is possible to get a small echo at 50,000 yards range when parasitic oscillations exist in the Mark 4 modulation generator.

Some of the features that are to be included in new radar equipments in order to provide more reliable operation are: standardized, interchangeable units, as the indicator console for the SG-3 and SR series of radars; ease of modernization by unit replacement; better resistance to shock and vibration; parts are more accessible for maintenance and adjustment; built-in voltage stabilizers; and more reliable parts so that fewer spare parts are required.

4. Performance Reports.

Radar performance reports and failure reports are bothersome to fill out. However, the great importance of the information contained in these reports requires that they be completed fully and accurately. The more information that can be returned to the Navy Department, the more effective radar can be made.

The reports that are sent in are analyzed thoroughly and a summary of the data presented is shown to the manufacturers, the designers, and the researchers in radar. Deficiencies of existing radar equipment are thereby made known to all agencies concerned with the equipment so that corrective measures can be taken quickly. Many of the changes that are being made currently result directly from suggestions and comments contained in performance reports.

Full reporting of equipment failures will inevitably result in more reliable equipment. When several reports indicate that a particular circuit element has failed, the reason is quickly investigated and remedial action taken.

An equipment log will be of great value in compiling data not only for reports, but also for the planning of a preventive maintenance schedule, and for obtaining a clear idea of the capabilities of the radar. Logging the ranges at which all classes of targets are detected will indicate both the general level of performance of the radar equipment and the ranges at which it is likely that various targets can be picked up.

5. Echo Box.

Ships that operate singly, especially submarines, often have no means of checking the overall operation of their radar. Thus, the only check that the set was operating correctly in the past has been that echoes are received; whether these echoes are the best that can possibly be obtained is indeterminate. Devices called echo boxes or phantom targets have recently been developed for use in tuning and testing the overall performance of nearly all types of radars.

The operation of the echo box may be explained simply by comparing it with a bell. When a bell is struck a sharp, hard blow, it rings loudly and continues to ring with decreasing intensity for a long time after the actual striking is completed. In a similar way, an echo box is made to oscillate when a strong transmitted pulse strikes the dipole antenna connected to the box. The oscillations continue for a length of time dependent on both the characteristics of the echo box and on the strength of the transmitted pulse that causes the box to oscillate. While the echo box is oscillating, or ringing, energy is radiated to the radar antenna, so that a large echo appears at the start of the sweep.

The receiver of the radar can be tuned to the transmitter, in the absence of any reflecting objects, by varying the receiver tuning controls to the point that produces maximum indication of the echo box ringing. In addition to aiding in tuning the radar, the length of the ringing time, in yards of range over which the signal extends, can be used as an indication of the performance of the system. The normal ringing time for each system must be determined when it is at peak performance. Then a quick check can be made of each radar system to determine the level of performance.

Since an echo box can indicate the level of performance of a radar, it is also of great use in analyzing troubles that decrease performance. Because of its great value in this respect, the echo box is now being provided as standard equipment with many types of radar.

CHAPTER VI

OPERATIONAL LIMITATIONS ON RADAR

A. Proficiency of operator:
Skill and experience; manipulation of controls; training.

B. False echoes:
Side lobes; multiple reflection echoes; blind zones; second trip echoes; phantom contacts.

C. Radar operation near land:
Blind zone near shore; radar shadows; aircraft over land; ranging on land; use of radar in piloting.

D. Spotting of shell splashes.

A. PROFICIENCY OF OPERATOR

1. Skill and Experience.

The amount of reliable data that can be obtained from any radar is dependent to a great extent on the proficiency of the operator. It is admittedly difficult to operate a radar with a high degree of effectiveness under all conditions. Therefore, the operators must combine high native intelligence, good visual acuity, manual dexterity, and great concentration with an intense interest in the work if radar is to be used to maximum benefit. To become proficient, the operator must practice continually.

The more the operator is able to understand about his radar equipment and about the tactical situation in which it is used, the more useful will be his performance. Many peculiar results have been obtained with radar that are variously attributed to phantoms, pixies, gremlins, and the like for want of a reasonable explanation for their occurrence. If the operator understands fully the limitations of his radar and knows the disposition of nearby friendly vessels, he will often be able to recognize the false character of many types of phantom contacts.

Long experience in observing a radar indicator enables the operator to notice many minute variations in the echo that are not apparent to a less skilled man. By noting these small variations, the operator is often able to estimate the size and type of the target. For example, the pip from an airplane is different from that of a ship, and the pip from several planes in a group is usually different enough from that returned from a single plane to enable the operator to estimate the number of planes in the group. In at least one case, it is reported that a very alert operator has often been able to tell not only the approximate number of planes in a group, but also the type of plane by observation of only the radar indicator. Such a performance is extraordinary, of course, but it illustrates the excellent results that can be obtained by very close observation coupled with wide experience. An unskilled operator can see only range and bearing, and that perhaps erratically; a skilled man sees in each pip much information beyond the normal range and bearing measurements.

In general, a skilled operator can detect a target at a greater range than an unskilled operator. This ability results from very close observation of the scope and a "feeling" for the appearance of echoes that are lost in the grass to the untrained eye.

2. Manipulation of Controls.

For detection of targets at maximum range, the grass must show strongly on the A scope and the "snow" on the PPI. However, the tendency of many operators is to cut receiver gain to a low level in order to obtain an indicator presentation which is sharp, and which shows strong contrast between signals and background noise. This is a dangerous practice. Large signals may continue to show up well on indicators, but the ability of the operator to detect small signals can be greatly reduced. It is necessary that small targets, such as life rafts, buoys, periscopes, and airplanes, be detected at the greatest possible range.

There is no way to eliminate receiver noise entirely. It is always present in sets which are operating properly, but it may not show if the receiver gain is too low. Signals smaller than the noise add to the noise to make the grass higher or the snow brighter. By noting the small change in the appearance of the trace caused by this addition, a good operator is enabled to discern very weak echoes. However, these echoes, which are equal to or less than the noise voltage, cannot be seen if the noise itself does not show.

The curves in figure 125 illustrate the decrease in performance of an SF radar on a small target as the gain is reduced. Compare the curves showing the range on the A scope and the PPI with the curve that shows the grass height on the A scope. When the gain is reduced sufficiently to make the grass only

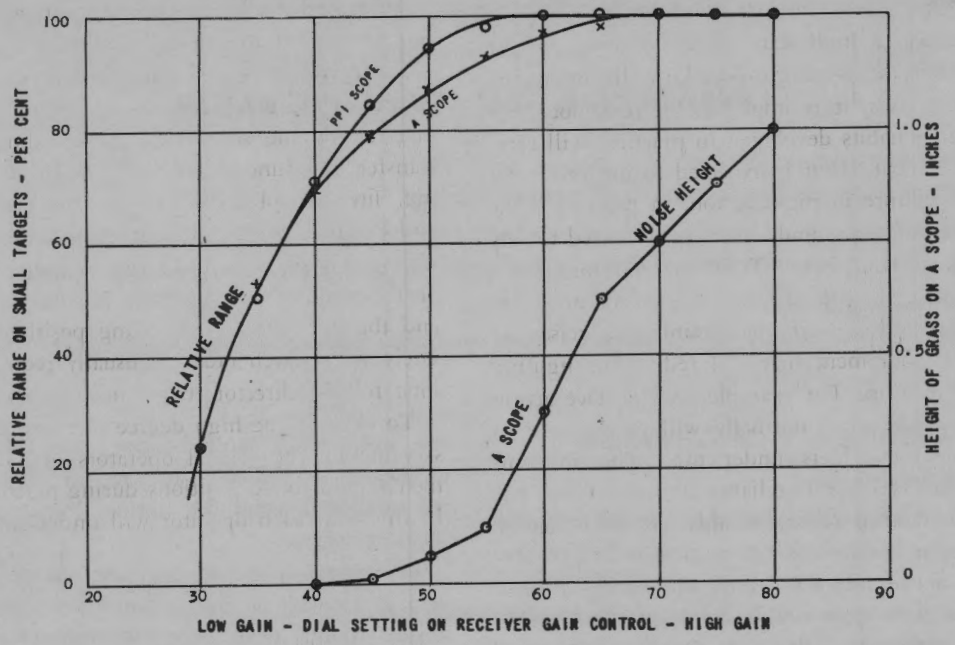

RELATIVE RANGE ON SMALL TARGETS - PER CENT
HEIGHT OF GRASS ON A SCOPE - INCHES
PPI SCOPE
A SCOPE
RELATIVE RANGE
NOISE HEIGHT
A SCOPE
LOW GAIN - DIAL SETTING ON RECEIVER GAIN CONTROL - HIGH GAIN

Figure 125—Variation in maximum range as function of receiver gain.

1/8 inch high (receiver gain control set at 55), the radar is approximately 95% effective. If further reduction in gain is made, the performance falls off very sharply. Similar effects will be noted in all radar equipment in which receiver gain is a manual control.

A properly trained operator will measure ranges always in exactly the same way so that his personal error is small and constant. As a result, the range and bearing data obtained by a good operator will be more consistent and more reliable than that obtained by an unskilled operator. The skill and dexterity developed by constant practice enable a good operator to measure a range and bearing quickly. Not only is it desirable that each operator be trained to measure ranges in precisely the same manner on each target, but it is also very desirable that all radar operators be trained in exactly the same operating procedures. On a battleship, for example, there may be two identical surface search radars. Unless the operators of these two sets measure ranges in exactly the same manner, considerable confusion may be caused by an apparent sudden change in range when a target is shifted from the forward SG radar to the after SG.

Radar equipment of recent design usually incorporates a circuit that automatically keeps the receiver tuned to the transmitter. The circuit which is used to accomplish this tuning is called AFC (Automatic Frequency Control). The use of AFC enables the operator to concentrate on observing the indicator, without his having to check the receiver tuning to insure peak performance. Other features of forthcoming radars that will simplify and facilitate the operator's job are: improved range scales so that there will be little necessity of shifting scales at a crucial phase of an operation; a range ring and a cursor on the PPI to enable both range and bearing to be read directly from the scope without the necessity of stopping the antenna; and a ship's head marker (SHM) to indicate the course of the ship on the PPI scope.

The setting of the controls of a radar is a function of the tactical situation in which the equipment is being employed. For example, a surface search radar may be used either for station keeping or for searching for surface targets. In station keeping the operator must normally use low gain to prevent masking of close-in targets by sea return. However, this low gain setting prevents detection of targets at long range. This conflict in requirements in the past often has restricted one radar to a single function or it has forced the operator to vary his controls so often that operational effectiveness is reduced. However, the use of Sensitivity-Time Control (STC) causes the receiver gain to be low for the first few thousand yards of the sweep and at whatever level the operator wishes to set it for the remainder of the sweep. Thus, the radar is enabled to perform several functions simultaneously without serious conflict. On one repeater PPI close-in targets can be observed on a short range scale so that the ship can maintain station, while at the same time other repeaters can be set to other range scales to search for targets beyond the formation proper.

3. Training.

To establish a high state of efficiency in the use of radar, constant training is necessary. In conducting training exercises, it is important to remember that the operating habits developed in practices will carry over into combat. If it is expected to use full radar control of gunfire in night action, in practices none of the director crew should ever be permitted to rely on any optical equipment. Training conditions, then, must be devised with a view to combat, and care must be taken to insure that training exercises do not involve equipment that will reduce the fighting ability of the ship. For example, in a surface action the fire control radars normally will be engaged in ranging on the targets under fire. Therefore, in training exercises chief reliance must *not* be put on the fire control radars as aids to navigation or station keeping.

In developing search techniques in training exercises, the importance of a thorough all-around search should be emphasized, for it is all too easy to fall into the habit of concentrating on the sector in which a target appears. Investigation of a contact to the exclusion of general search encourages the use of feints and deceptive tactics on the part of the enemy. Ships have been lost because an adequate search was not maintained around the full 360°.

Extensive training is required to enable the fire control or height-finding radar to get on a target detected by the search radar. Coordination of this transfer is a function of CIC. With adequate training, fire control radar can get on a surface target and begin to track it within 30 seconds to a minute after the position of the target is indicated. Because of the additional complexity introduced by altitude and the difficulty of measuring position angle accurately with search radar, it usually requires a longer time for the director to get on an airborne target.

To develop the high degree of coordination necessary among the several operators in a director, the men should rotate positions during practice exercises. In this way, each operator will understand the problems confronting the others. As a result, the time required to produce effective teamwork will be reduced.

In order to realize the full accuracy possible with fire control radar, the operators must practice making precise measurements of range and bearing. Since bearing accuracy often depends on matching pip heights, extensive practice in this operation is neces-

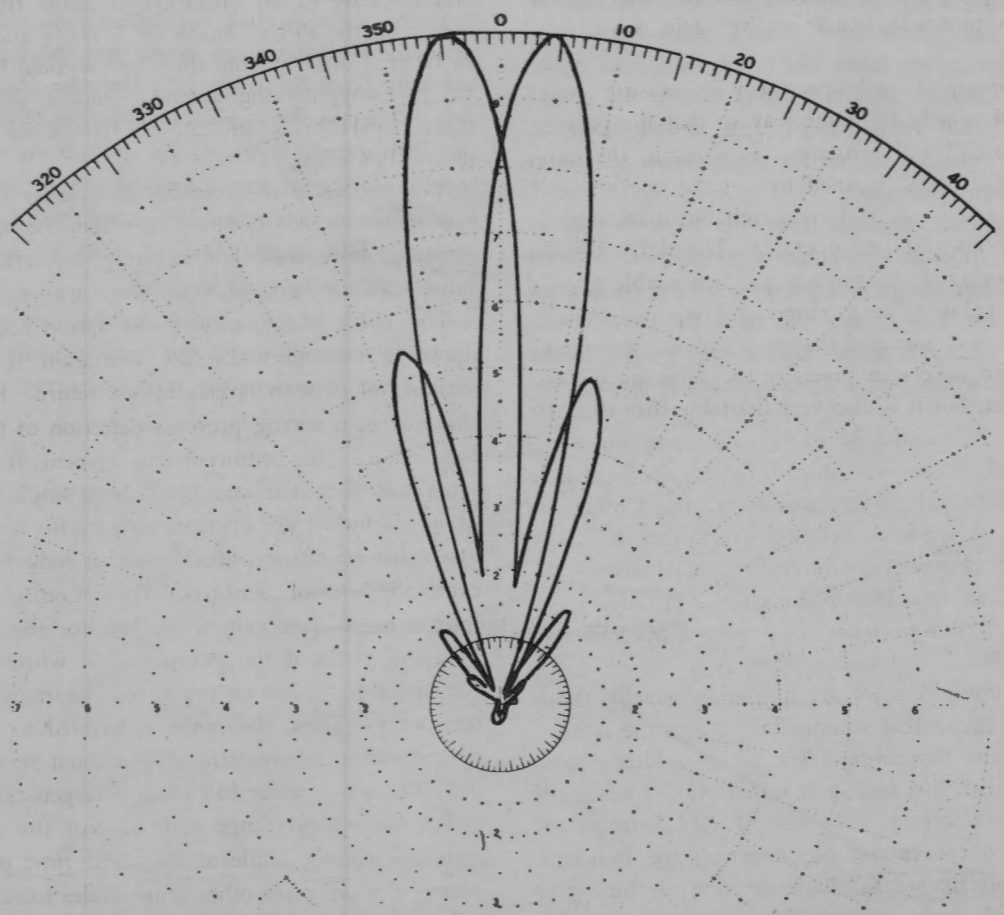


Figure 126—Radiation pattern of a lobe-switching fire control radar.

sary to develop the operator's judgment to the point where reliable bearings can be determined within the rated accuracy of the equipment. Accurate pip matching is difficult, and it cannot be done well by inexperienced personnel.

B. FALSE ECHOES

1. Side-Lobe Echoes.

Although a directional antenna radiates energy principally in one beam, a small fraction of the energy is radiated in other directions. This small radiation is confined generally to small beams, called minor lobes or side lobes, which are displaced from the axis of the main radiation. In addition, since the reflector is not perfect, some energy is radiated in a direction 180° away from the direction of the main lobe. The radiation pattern of an air search radar antenna is shown in figure 92, and in figure 126 is shown the pattern of a fire control radar that employs lobe switching. Note in figure 126 that large side lobes exist at 345° and 015°, and smaller side lobes are at 35° and 50° each side of the antenna axis.

In spite of the fact that these minor lobes are usually small, they contain enough energy to produce echoes from targets at short range when the receiver gain is high. Side lobe echoes, even from relatively large minor lobes like these shown in figure 126, are seldom received from targets at ranges beyond 10,000 yards. With most radars, however, side lobe echoes will not be troublesome at ranges greater than 5,000 yards.

If echoes are obtained from side lobes as well as the main lobe as the antenna rotates, an isolated target at close range will produce several spots on a PPI. All of these echoes will be at the same range, but they will cover an arc on the screen equal to the angle over which minor lobes appear. If the receiver gain is high and the target very close, the resultant poor bearing resolution may cause the several echoes to merge, forming a complete circle on the screen. Normally, side lobes are not strong enough to produce this extreme condition, but often an arc of 50° to 120° length will be seen.

In the case of an isolated target, the effect of side lobes is easy to evaluate. The echoes are all at the same range, and they are symmetrically placed about a central bright echo. Side lobe echoes are weaker than main lobe echoes, but this distinction often may not be apparent. With high gain, echoes from both main and minor lobes may be limited in the indicator so that they all produce spots of equal intensity on the PPI. If the gain is reduced, the side lobe echoes in general will be less intense and of less angular width than the main echoes.

If the operator is thoroughly familiar with his equipment, he will know the range at which to expect confusion from side lobe echoes and he will know the angular separation from the main echo at which side lobe echoes normally appear. If the system is improperly tuned, however, the size of the side lobes may be increased and their position shifted. The technician should be able to correct this condition by retuning the radar.

If the radar is close to a convoy or a formation of many airplanes, each target may produce echoes not only from the main lobe but also from several side lobes. In the resultant confusion of echoes on the PPI screen, it would be difficult to select the correct bearing of any individual target, and almost impossible to determine how many real targets are present. This same effect is often a handicap to reliable station keeping by radar.

The effect of side lobes can be very easily reduced by turning down the receiver gain, but this adjustment is undesirable from the search point of

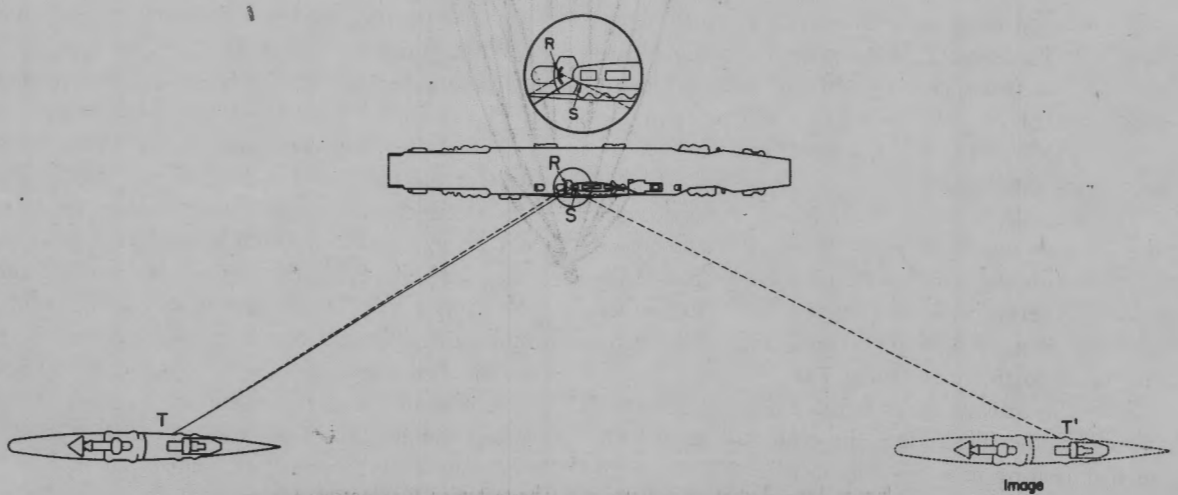


Figure 127—False contact caused by reflection from ship's structure.

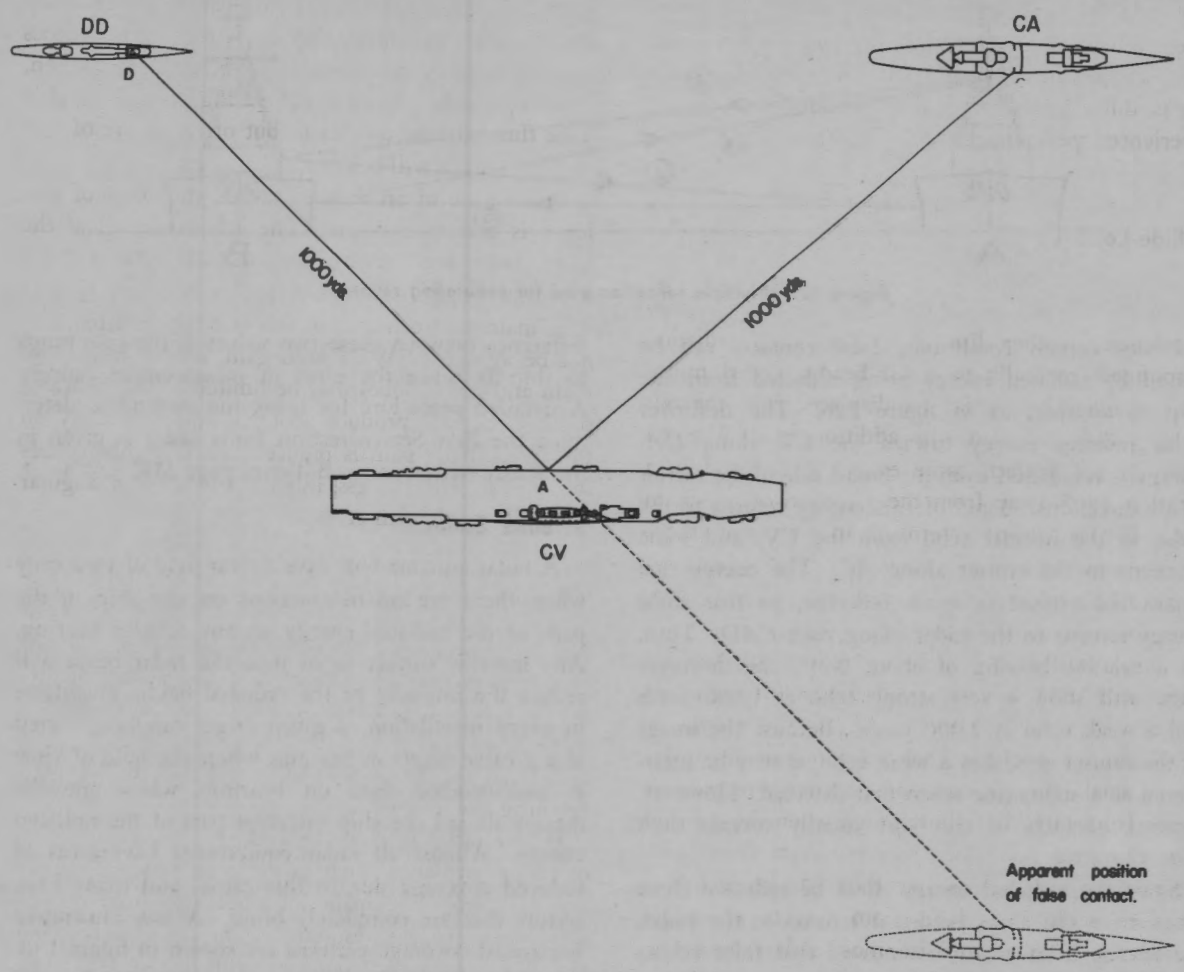


Figure 128—False contact caused by reflection from nearby ships.

view. However, Sensitivity Time Control will be of great help against side lobe echoes because it reduces receiver gain over only the first few thousand yards of the sweep, and then restores the sensitivity to normal for search over the remainder of the sweep.

2. Multiple Reflection Echoes.

The energy radiated from a radar antenna sometimes may be deflected from its normal straight path by reflection from some part of the ship's structure. This reflected energy can produce echoes from targets at short range, but the bearing on which the echo is indicated is false.

For example, in figure 127, *R* is a radar antenna and *T* is a nearby target. When the antenna is directed into the ship's structure, as along *RS*, the radiated energy will be reflected from the superstructure along *ST* to the target, and echo energy can return to the radar along *TSR*.

Since the antenna is trained to approximately 030° relative in the illustration, the echo will seem to be on that bearing at a position such as *T'*. The indicated range of the false contact will be almost the same as the true range because *RST* is almost the same length as *RT*. The echo is real, of course, but the contact is false since no real target exists at the range and bearing shown by the radar. The true position of the target will be indicated when the antenna beam is directed along *RT*, at a relative bearing of approximately 150°.

When the operator becomes thoroughly acquainted with his equipment, he will know the bearings on which to expect doubtful echoes. One very common cause of false contacts on destroyers results from mounting the SG antenna on a platform just forward of the mast. When the antenna is trained aft, echoes are often returned from the next ship *ahead* in column. If the operator is aware of this possibility he will not be confused by its occurrence. However, a very simple remedy has been found for eliminating phantom echoes caused by reflection from the mast. It consists of a metal screen reflector which is so mounted that the energy that strikes it is reflected straight up. This does not remove the blind spot caused by the mast, of course, but it does prevent echoes from being returned on a false bearing.

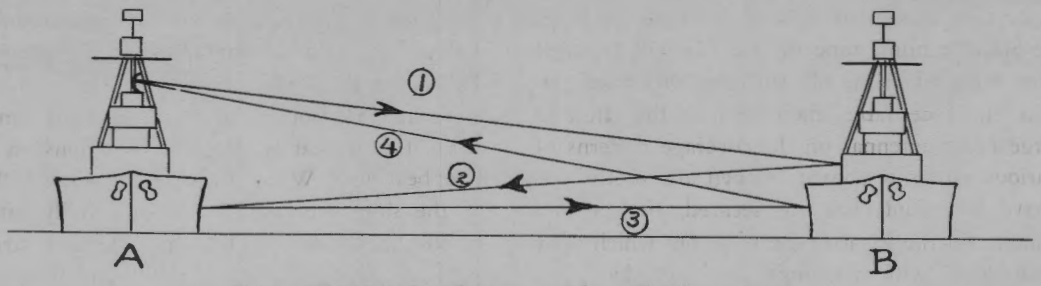


Figure 129—Multiple reflection used for calibrating radars.

Under certain conditions, false contacts can be caused by radiated energy being reflected from one ship to another, as in figure 128. The destroyer radar radiates energy toward the CV along *DA*. Energy is reradiated from the broad side of the carrier in all directions. Some of this energy returns to the radar as the normal echo from the CV, and some proceeds to the cruiser along *AC*. The energy that strikes the cruiser is again reflected, so that some energy returns to the radar along path *CAD*. Thus, on a relative bearing of about 040°, the destroyer radar will show a very strong echo at 1,000 yards and a weak echo at 2,000 yards. Because the image of the cruiser produces a weak echo, it may be interpreted as a submarine when first detected. However, plotting contacts of this sort usually reveals their false character.

Since the radiated energy must be reflected three times from the ships before it returns to the radar, the energy is so greatly attenuated that false echoes caused by multiple reflection can be encountered only when ships are in close formation. If the carrier in the illustration yaws or rolls, the false contact will fluctuate badly and perhaps disappear completely. In general, rather small changes in the relative positions of the ships involved will cause the false contact to disappear.

A slightly different case of multiple reflection has been found to be very useful in calibrating radars. When two ships are steaming abreast on parallel courses, multiple reflections can take place between them in the manner shown in figure 129 if the ships are separated by no more than 3,000 yards. The transmitted pulse is sent out along path ①, and it is reflected from ship B. Part of the reflected energy returns to the radar along path ① and part of the energy may follow a path such as ②. This energy in turn will be reflected back toward ship B along path ③, where it is again reflected, following path ① back to the radar. The radar indicator will show a strong echo at the range of ship B and a weak echo at twice the range. If the inherent error in measuring range is E and the true range is R, the radar indicates a range of R + E on the strong echo and a range of 2 R + E on the weak echo. The difference between these two values is the true range to ship B, since the error in measurement cancels. A detailed procedure for using the method to determine the Zero-Set correction for a radar is given in the Radar Maintenance Bulletin, page MK 3/4 5–12.

3. Blind Zones.

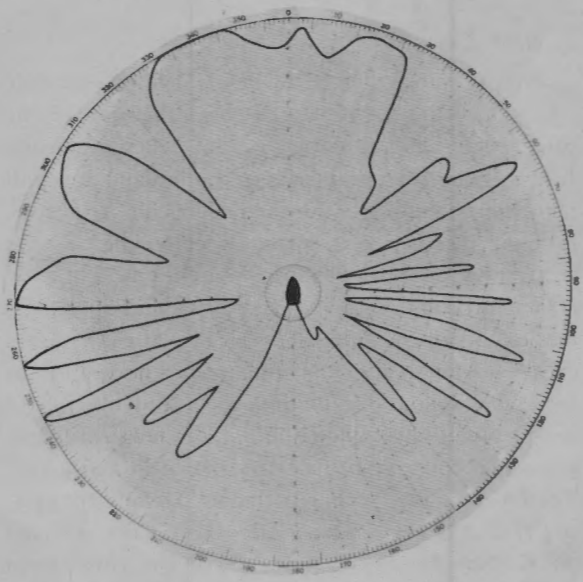
A radar antenna will have a clear field of view only when there are no obstructions on the ship in the path of the radiated energy on any relative bearing. Any metallic surface in or near the radar beam will reduce the intensity of the radiated field. Therefore, in every installation, a given target can be detected at a greater range on bearings where the field of view is unobstructed than on bearings where metallic masses aboard the ship intercept part of the radiated energy. Almost all radar equipments have areas of reduced coverage due to this cause, and many have sectors that are completely blind. A few illustrative horizontal coverage patterns are shown in figure 130. These curves may be interpreted as showing the relative ranges at which a particular target is first detected on various relative bearings. In B the coverage is practically perfect since the antenna is mounted up in the clear where no obstructions are present. However, the other patterns show, in varying degrees, how the signal returned from a target can vary as a function of relative bearing. These patterns are not necessarily typical of all classes of ships; they are extreme cases which are intended to show how poor the coverage can be in some installations.

Patterns of this sort can be taken by observing the height of the echo returned from a remote, isolated target as the ship turns. To avoid error, the ship should turn slowly in the smallest possible circle and the target should be stationary at a range of 30,000 yards or more. Although the pattern can be determined more accurately with special test equipment, a few simple tests involving only the radar and an isolated target will indicate satisfactorily blind zones and areas of reduced coverage.

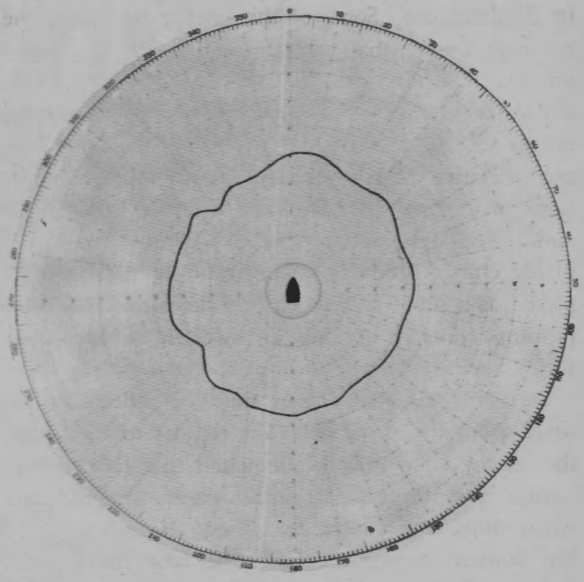
In some installations it will be found that the extent of an area of reduced coverage will be dependent on the position of another radar antenna. When the SK antenna, for example, is trained so that

it intercepts a maximum amount of energy radiated by the SG, the blind zone for the SG will be more extensive than when the SK is turned 90° from this position. It is desirable, then, to note the effect of the large radar antennas on the coverage patterns of the various radars on board. When any of the sets that have large antennas are secured, they should be trained to the relative bearing on which they interfere least with thorough coverage by other equipment.

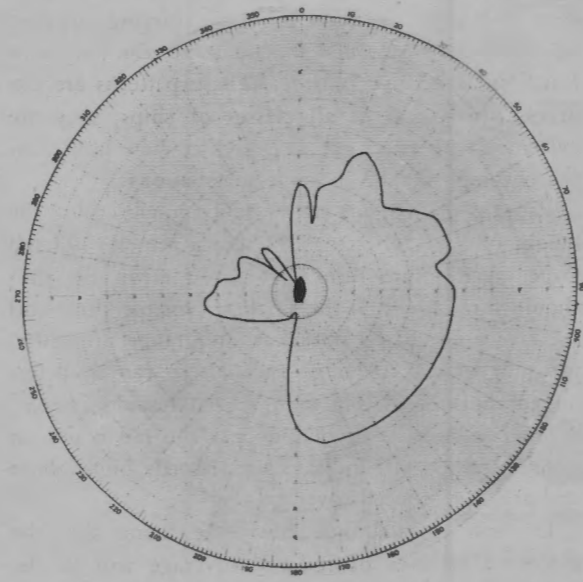
The only cure for a blind zone caused by interference from the ship's structure is to relocate the antenna. Since most naval vessels are now equipped with several radars, it is likely that only one antenna can have a clear field of view. For example, figure 131 shows two photographs of the antennas installed on the U.S.S. *Yorktown*. It is immediately apparent that not all of these antennas can have a field of view that is free of obstructions on all relative bearings. When the SM looks over the stern of the ship, the beam is almost wholly intercepted by the SK antenna. Thus the SM has a large blind zone aft. Similarly, both the SK and the after SG-a have blind zones forward, while the SC-2 has greatly reduced coverage over a wide angle to port, depending partly on the position of the SK antenna. Since it is not possible for all antennas to be in the clear because of the limited number of possible posi-



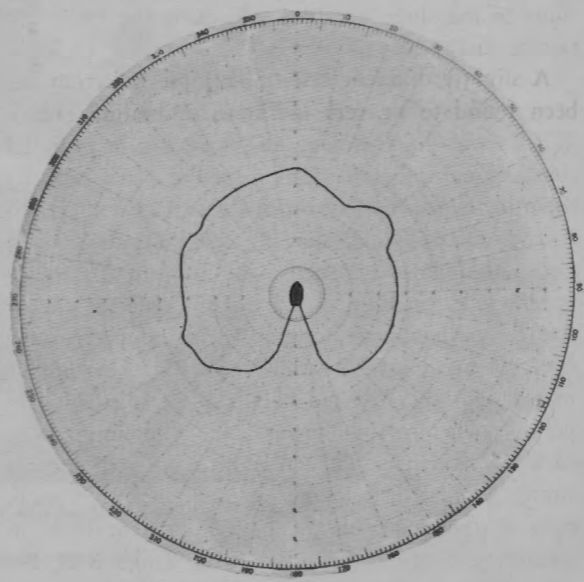
A. Height-finding and low-angle search radar (SM) on CV.



B. Ajr search radar (SK) on BB.

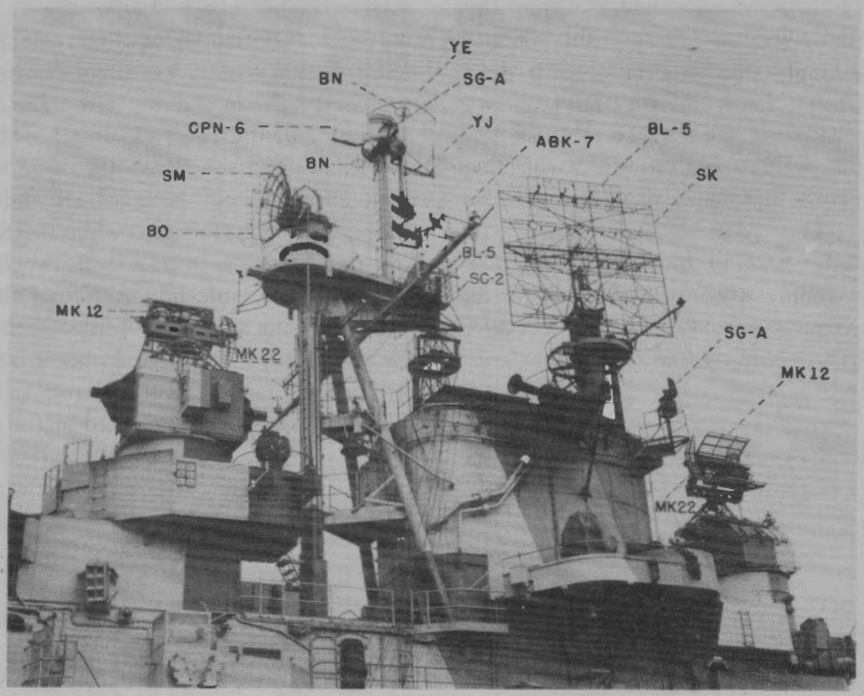


C. Air search radar (SC-1) or CV.

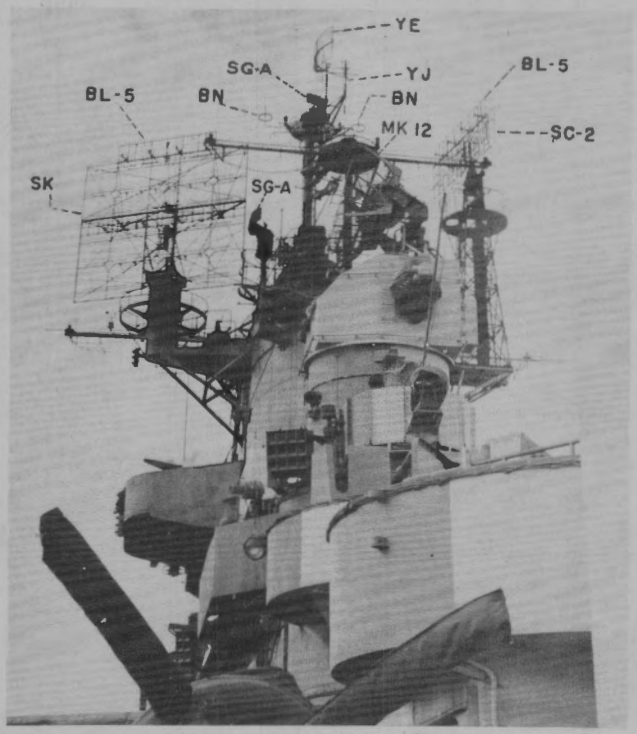


D. Forward surface search radar (SG) on BB.

Figure 130—Horizontal radar coverage patterns.



A. Broadside view of island from flight deck.



B. View of island from flight deck looking forward.

Figure 131—Superstructure of U.S.S. "Yorktown."

tions in the superstructure, the radars should be installed so as to minimize the reduced coverage areas and the totally blind zones. Areas in which good coverage is obtained should overlap insofar as possible, so that a single ship may be able to detect both air and surface targets over the full 360°.

Another type of blind zone exists for all radars above the maximum position angle at which the vertical width of the antenna will permit detection of targets. The size of this zone is dependent principally on the characteristics of the antenna itself, and it is affected only a little by the site of the antenna. For example, the SG radar cannot detect any targets above a position angle of about 8°.

4. Second-Trip Echoes.

Radio waves travel through the atmosphere at a speed of 328 yards per microsecond. However, a radar pulse must travel out to the target and back again, so that the effective velocity of a radar pulse is 164 yards per microsecond. The maximum range that the radar can measure directly is then the interval between pulses, in microseconds, multiplied by 164 yards per microsecond.

A target that is 230,000 yards away normally will not be detected by either fire control or surface search radar. If the target is high land and the weather is such as to produce a duct, the radiated energy may be guided to the land and the reflected energy guided back to the radar. Under these conditions, the echo may show up on the SG or Mark 4 indicators, but since neither equipment uses a range scale long enough to measure the range directly, the indicated range will be incorrect. If the SG uses a repetition rate of 800 pulses per second, the interval between pulses will be 1,250 microseconds, which is equivalent to 205,000 yards range. In figure 132 the land target is 230,000 yards away so that the time of flight of the pulse is longer than the interval between pulses. As a result, nothing shows on the first sweep, and in A the land echo shows at 25,000 yards on the second trip of the electron beam across the face of the indicator. To get the correct value of the range, the 205,000 yards represented by the interval between pulses must be added to the indicated range.

It is apparent, then, that the range at which this target appears depends on the repetition rate of the radar. For example, in B the SG sweep is shown for a repetition rate of 750 pulses per second. In this case the pulse interval represents 218,700 yards, so that the indicated range is 11,300 yards. Thus, the simplest method of showing up a false contact caused by a second trip echo is to change the repetition rate. However, this is not possible with all radars, so that a second check would be to range on the target with other radar equipment. In figure 132C is illus-

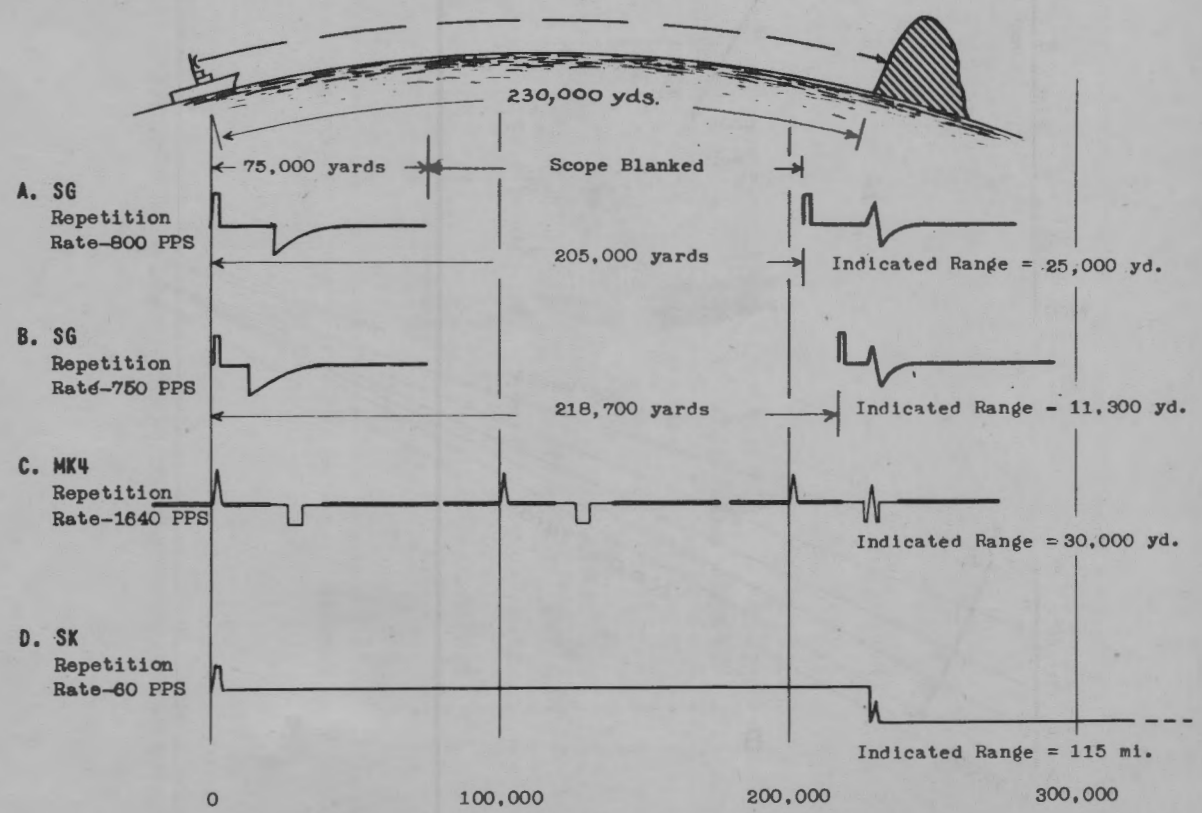
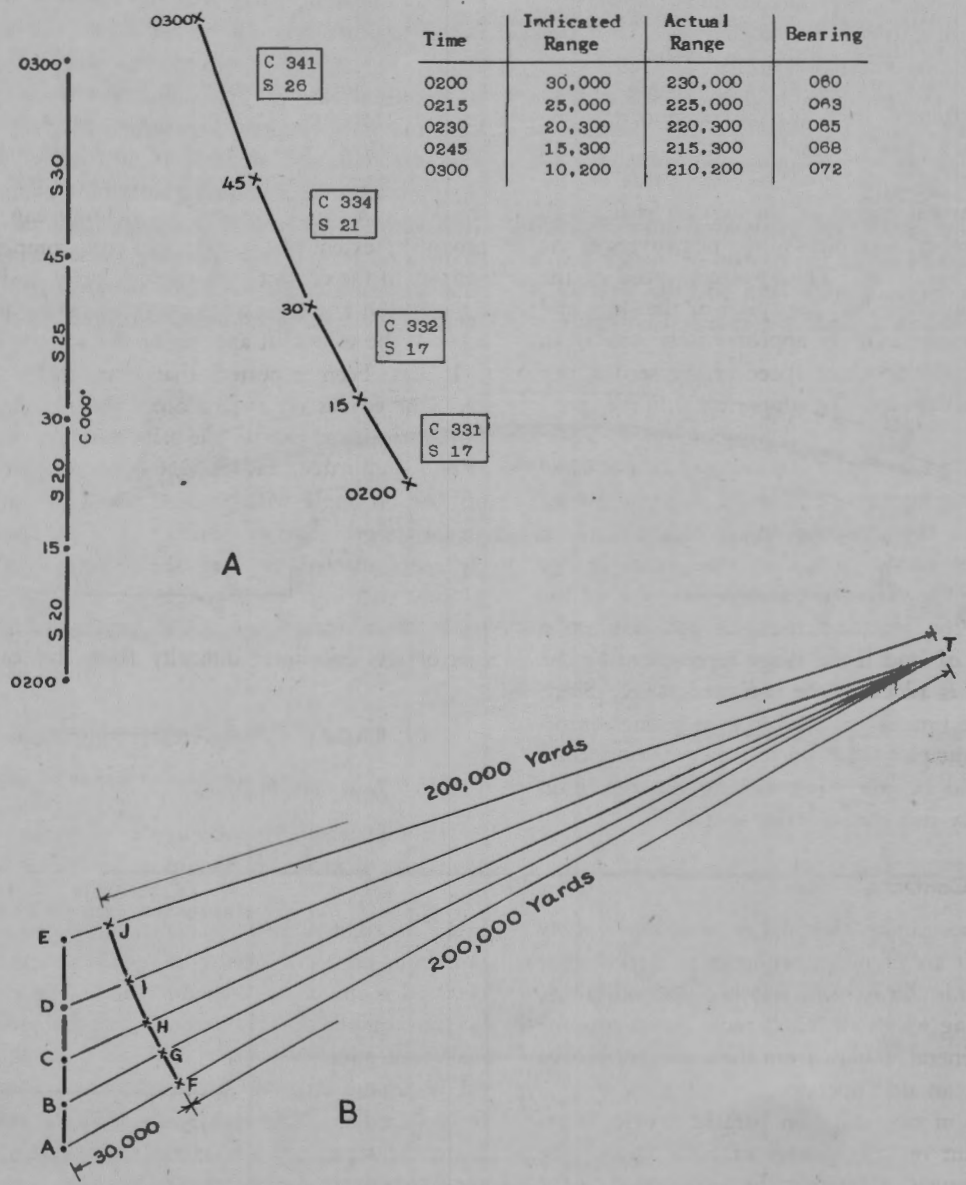


Figure 132—Second trip echoes.

trated the sweep of a Mk 4 radar which is ranging on the same land target. Because one pulse interval represents 100,000 yards with this equipment, the echo will appear on the third sweep. The indicated range is 30,000 yards. In D is shown part of the SK sweep. This equipment uses a 60 cycle pulse rate so that the pulse interval represents 2,733,000 yards, or 1,367 nautical miles. The 375-mile sweep on the SK, which is possible only on a radar having such a low repetition rate, is able to indicate directly the range to the land. Therefore, if all three ranges were compared, the false contact would be evaluated as a second or third trip echo. In some cases it will not be possible to check second-trip echoes on an SK or SC-2 because the atmospheric conditions that cause trapping of L and S-band radiation may have no effect on P band. When this occurs, the SK will not show the distant target at all. In a few rare cases unusually strong trapping conditions may cause second-trip echoes even on sets that have range scales 400 miles long. However, it usually is quite safe to assume that second-trip echoes are impossible with a radar whose pulse rate is less than 200 pulses per second.

It is interesting to note that a phantom enemy was fired on for over an hour as a result of a false contact caused by second-trip echoes. In this case, however, an unfortunate coincidence occurred to prevent thorough checking of the contact. The SG repetition rate was almost exactly half that of the Mark 3 and 4, so that both equipments indicated the same range—one on the second trip, the other on the third. Comparison of figure 132A and C will indicate how this mistake occurred. Another factor that prevented



Time	Indicated Range	Actual Range	Bearing
0200	30,000	230,000	080
0215	25,000	225,000	083
0230	20,300	220,300	085
0245	15,300	215,300	088
0300	10,200	210,200	072

Figure 133—Geographical plot of second trip echo contact.

a complete check of this contact was the fact that the duct formed by the weather apparently was too shallow to guide the P-band energy of the SK, while the L and S-band energy of the Mark 3 and SG was guided. As a result, the SK did not detect the land, which prevented a direct indication of the range of the contact.

A geographical plot can be used as an auxiliary means of evaluating a contact suspected of being a second trip echo. As an example, assume that a land mass is 230,000 yards away and that the pulse interval of the radar represents 200,000 yards. The indicated range of the initial contact will then be 30,000 yards. As the ship moves, the actual range to the land will change only a little, but the indicated range varies rapidly. Consequently, plotting the ranges and bearings indicated by the radar produces a track for the contact, as in figure 133A. If the same data are plotted to a smaller scale, and the 200,000 yards added to each indicated range, the land target will plot at a stationary position at *T*, as in figure 133B. It is evident from *B* that, for the radar of this example, the track of this second trip echo must always plot as an arc of a circle of 200,000 yards radius. Thus the apparent course of the contact changes in an orderly manner, regardless of the maneuvers of the ship carrying the radar. The apparent speed of the contact is always less than the speed of the ship, and since the triangle TGE is approximately similar to triangle TBA, the apparent speed of the second trip echo contact always must be proportional to the speed of the ship.

Thus, a second trip echo contact may be evaluated as such by changing the speed of the ship and noting the change in the apparent speed of the contact. Other features of the plot that may assist in the evaluation are the progressive change in course of the contact, and the fact that the plot can indicate a definite point of land if the range represented by the pulse interval is added to the indicated range. Since a considerable time is required to gain enough information from the plot for a conclusive evaluation, chief reliance should be placed in varying the repetition rate to identify this type of false contact.

5. Phantom Contacts.

Radar echoes can be returned from a large variety of objects that are of no consequence as targets. For example, clouds, birds, fish, weather discontinuities, and intersecting wakes all reflect radar pulses to some extent. In general, echoes from these sources can be recognized by an alert operator.

The wakes of two ships on parallel courses intersect at a point on the quarter of both ships. The intersection travels at roughly the same speed as the ships, and can produce a fluctuating echo that will remain at nearly the same range and bearing as long as the relative position of the ships is unchanged.

In some cases, heavy waves at close range produce echoes that have fairly high rates of speed. The size of the echo and the speed at which it approaches may temporarily lead the operator to believe that the wave is a motor torpedo boat, or some such small, fast vessel.

The echoes from flying fish or birds fluctuate rapidly as a rule. In addition, the behavior of birds is usually so different from that of any other type of airborne target that observation of the movement of the object should reveal it as a bird. Since birds and flying fish are relatively small, they can return echoes only at short ranges.

Clouds and weather discontinuities vary greatly in character, so that their ability to reflect radar pulses is far from constant. In general, echoes produced by atmospheric phenomena fluctuate rapidly and they produce a hazy indication on the cathode-ray tube screen. (See figs. 102 and 103.) In a few cases, however, clouds may produce sharp, bright indications that may seem to be reflected from real targets. Cloud contacts can be recognized by determining the approximate extent of the reflecting area, comparing the velocity of the contact with wind velocity, and finding the position angle, in addition to observing the character of the echo that appears on the screen.

It has been reported that star shells produce excellent echoes on radar. Since the parachute falls slowly at almost exactly the same range as the target being illuminated, radars that have poor resolution in position angle will be unable to range accurately on the target. Surface search radars are usually not seriously affected by star shells because the projectiles pass quickly through the narrow antenna beam. However, the air search radars and some fire control sets encounter difficulty from this cause.

C. RADAR OPERATION NEAR LAND

1. Blind Zone Near Shore.

The limitations imposed by the range and bearing resolution of most radar equipment prevent the detection of targets close to shore. If the radar beam looks at right angles to a straight shore line, the minimum offshore distance at which a target can be detected is the distance required for range resolution by the equipment. However, when the radar beam makes an angle other than 90° with the shore line, the minimum offshore distance at which a target can be detected is controlled by the bearing resolution. Since the separation of targets required for bearing resolution is generally greater than that required for

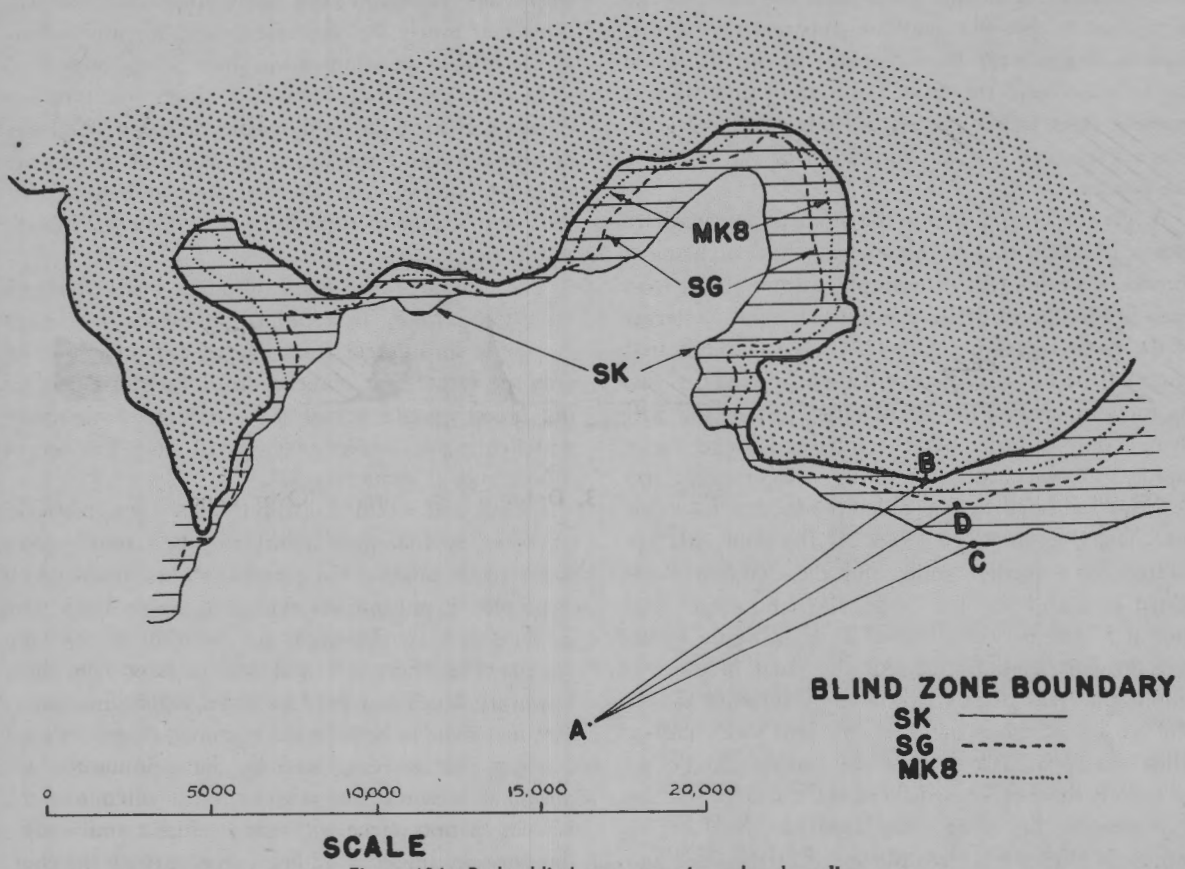


Figure 134—Radar blind zones near irregular shore line.

range resolution, a fairly extensive blind zone exists close in to shore.

An irregular shore line is shown in figure 134 along with the blind zones near the shore that exist with radars of different beam widths. The radar is assumed to be at point *A*. Since an echo will be received over an angle of train approximately equal to the beam angle, each point on the shore produces an arc on the PPI. As a result, the shore line seems to extend out to sea a distance dependent on the angle at which the radar beam strikes the shore. For example, when the axis of the SK beam lies along *AB*, any target that lies on the arc *BC* will be hidden by the echo from the land at *B*. However, if a radar with a narrower beam, and consequently with better bearing resolution, is used, the extent of the blind zone close to shore will be reduced. Therefore, an SG radar at point *A* could detect a target at point *D* instead of at *C*, and the Mark 8 could detect a target even closer to the land. Where the edge of the radar beam does not strike land at a particular range, the boundary of the blind zone is determined by the range resolution of the radar. For simplicity, it has been assumed that the range resolution is approximately 500 yards for each of the three radars illustrated in figure 134.

The extent of the blind zone for any shore line can be approximated if the position of the ship relative to the shore is known, and a chart of the area is available. For each bearing, a point is plotted at the range of the land, but offshore by an angle equal to the resolution angle. Thus, if the resolution angle of the SK is the 10° angle *BAC*, and the antenna is trained to a bearing of *AB*, it will be impossible to detect a target at the same range as point *B* until the antenna is turned away from the land by an angle great enough to eliminate the echo from the shore line. It is usually considered that this angle is the resolution angle of the radar, so that at the particular range and bearing shown, point *C* represents the closest point to land that an SK radar can detect a target. The outer boundary of the blind zone can be determined by plotting such points for all possible bearings. However, when the beam is directed perpendicular to the shore, bearing resolution does not affect the blind zone. Therefore, a contour representing the range resolution must be drawn to cover the areas where bearing resolution does not affect the blind zones.

This method is approximate only, because the echo is not necessarily returned from the junction of water and land. Often high land back from shore

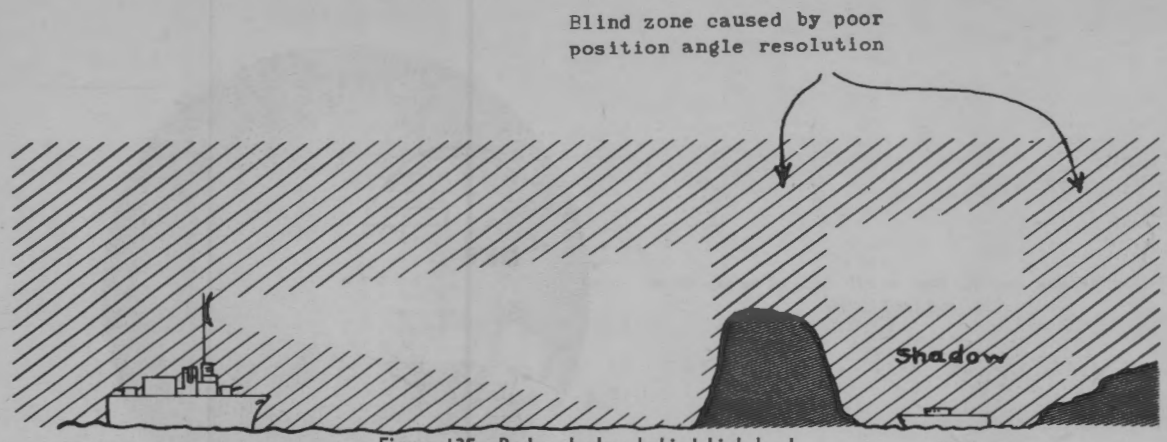


Figure 135—Radar shadow behind high land.

produces the echo that is seen on the radar, while a low beach is not detected. In places where the shore line is a clear low beach, surface targets may often be detected much closer to shore than the method used in figure 134 would indicate. However, when the shore is steep, the great size of the land causes the bearing resolution to be poorer than normal because echoes are returned by the land even when the antenna axis is turned away by more than half the beam angle. As a result, in places where the shore line reflects radar pulses very well, the resolution angle used in determining the blind zone should be greater than simply half the beam angle.

In general, little decrease of the blind zone can be effected by the use of low radar sensitivity because the barges, sampans, or PT boats that are likely to operate close to shore cannot be detected with low gain.

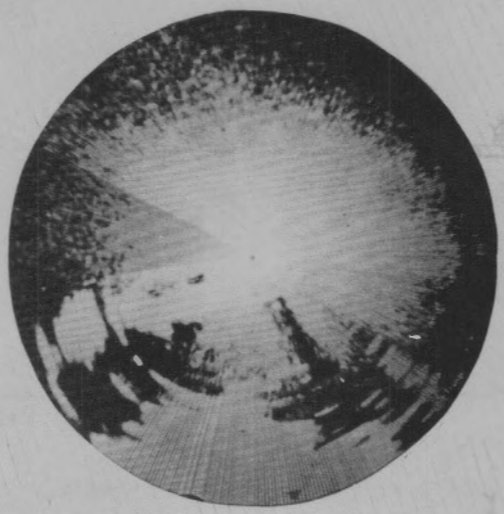
2. Radar Shadows.

If the promontory shown at the right of figure 134 is high ground, the blind zone contours shown in the cove behind the headlands will be incorrect. This region will be in a radar shadow, as illustrated in figure 135, and a target behind the promontory will not be detected by any radar on the ship. High land blocks the radiated energy, preventing it from striking any low points beyond. Thus, high land produces a blind zone irrespective of the resolution characteristics of the radar.

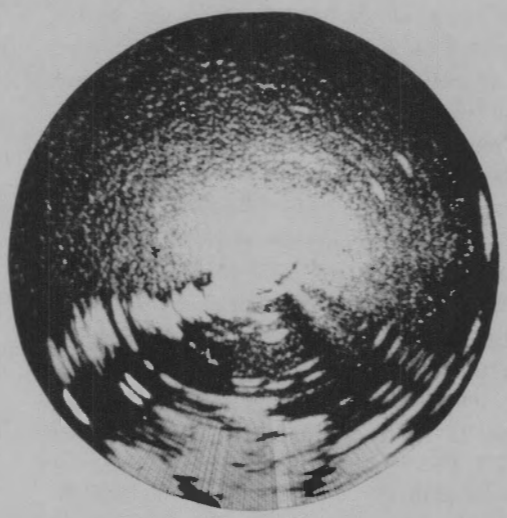
In figure 135, notice that there is shown, directly over the land masses, a blind zone caused by the poor position angle resolution of the radar. In most search radars, the antenna cannot be tilted. Therefore, if a large target is detected at a given range, its echo will mask the echo from any other target at the same range even when the two targets are at different altitudes. Thus, in figure 135 a blind zone exists above the land, so that an airplane cannot be detected in this area.

3. Detection of Aircraft Over Land.

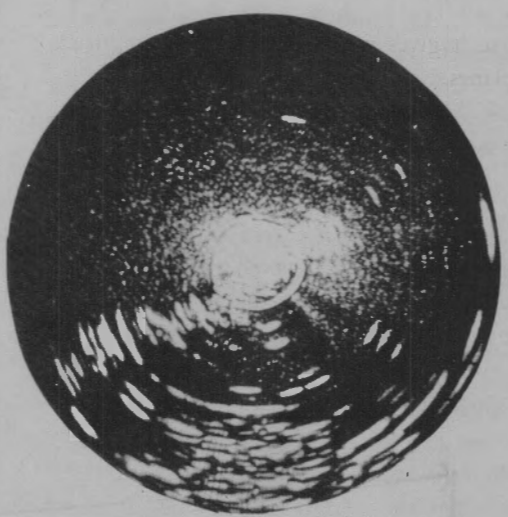
As a result of their poor position angle resolution, search radars generally are not able to detect airplanes that approach from over land. Since the Japs are apparently aware of this limitation of radar, operators must be especially diligent in observing the echoes returned from land for the slightest indication of a moving target. It is very difficult to observe the slight changes in the indications produced by airplanes flying over hilly land when the antenna is in constant rotation, since the echoes are retraced only intermittently, making it hard to distinguish the desired echo in the clutter produced by the reflections from the land. Any device which can reduce the amount of clutter without materially reducing the desired echoes will therefore aid considerably in allowing the operator to detect moving targets over a land mass. The Instantaneous Automatic Volume Control and Fast Time Constant coupling circuits that are being provided in radars of recent design will prove to be valuable not only as anti-jamming devices, which was their original purpose, but as anti-clutter devices as well. For example, in figure 136 three photographs of an experimental radar PPI are shown. In *A*, nearly the whole screen is covered by sea return, and the land at the bottom of the picture shows as a solid mass of echoes. When IAVC is used, in *B*, the sea return is made less severe, and the land mass is broken up to some extent. Finally, with the combination of IAVC and FTC, shown in *C*, the land mass is broken into many discrete pips and the sea return is greatly diminished. An operator would have a fair chance of detecting an aircraft that approaches over land if the echo can be broken up as in *C* because he could watch for targets moving in the cluttered area. To be sure, it is still a difficult task, but the improvement produced by these new circuits makes it a possible one. Even with these improvements, it may often be desirable to assign



A. Receiver normal. Most of PPI obscured by sea return and land clutter.



B. IAVC turned on. Note the slight improvement in the appearance of the cluttered areas on the scope.



C. Both IAVC and FTC turned on. Note that the sea return is considerably reduced and that the land clutter is broken into many small pips.

Figure 136—Effect of IAVC and FTC on ground clutter on PPI scope.

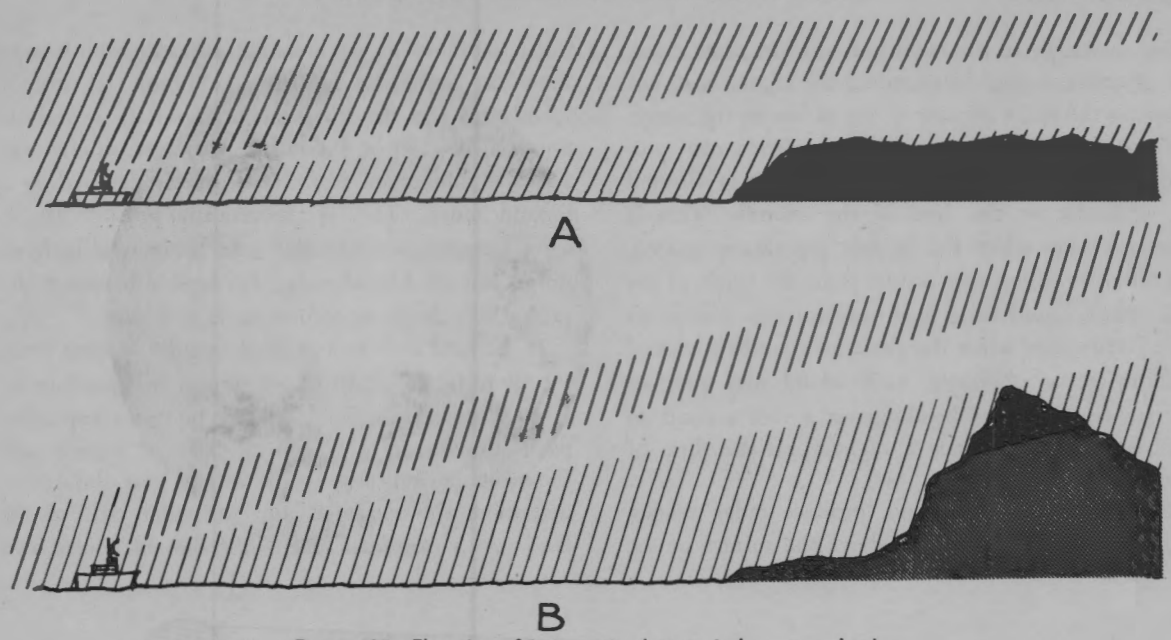


Figure 137—Elevation of antenna to detect airplanes over land.

one radar to search carefully over the land, using manual control of the antenna, when the ship is anchored close to shore, since there is a better possibility of seeing a fast-moving target on the A scope than on the PPI under these conditions.

If the radar antenna can be elevated, the beam can be pointed so that it just misses the land. Thus in figure 137A, good protection is afforded by the radar, while if the land rises sharply, as in figure 137B, the operator must wait to see if any planes come over the peak of the land. The chance of missing the target under these conditions is great, so that it is very difficult to maintain an effective search.

If the radar gain is reduced to the point at which land echoes do not saturate the receiver, friendly planes may be tracked over land by following their IFF responses. This method is not highly reliable, and of course it gives no indication of the approach of enemy planes.

4. Ranging on Land.

The maximum range at which land can be detected by radar depends to a great extent on the character of the land. Sand spits and smooth clear beaches do not show up on radar at ranges beyond one or two miles because such targets have negligible area that can reflect energy back to the radar. Two radiated rays from the antenna are shown striking a smooth sand spit in figure 138. Since the target is so low in the water and because it is flat, these rays are reflected on beyond the target. If waves are breaking over the sand bar or on the beach, echoes may be returned from the surf. However, the waves may break well out from the actual shore, so that ranging on the surf may be misleading when a radar position is being determined relative to the beach. As the tide rises and falls, the apparent shore line, as determined by radar ranges on surf, will appear to shift.

Mud flats and marshes generally reflect radar pulses only a little better than a sand spit. The weak echoes that are received at low tide disappear at high tide. Mangroves and other thick growth may produce a strong echo. Therefore, areas that are indicated as swamps on a chart may return either strong or weak echoes, depending on the density and size of the vegetation growing in the area.

When there are sand dunes covered with vegetation well back from a low smooth beach, the apparent shore line determined by radar will be along the line of the dunes rather than the true shore. Under some conditions, sand dunes may return strong echo signals because the combination of the vertical surface of the vegetation and the horizontal beach may form a sort of corner reflector.

Lagoons and inland lakes generally show as blanks on a PPI scope because the smooth water surface re-

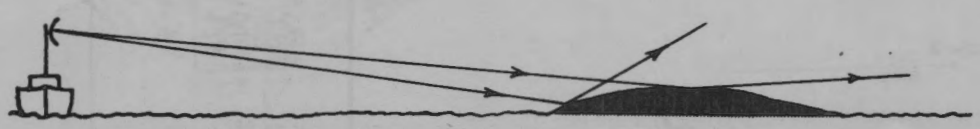


Figure 138—Radar reflection from sand spit.

turns no energy to the radar antenna. In some cases, the sand bar or reef surrounding the lagoon may not show on the radar because it lies so low in the water.

Coral atolls and long chains of islands may produce long lines of echoes when the beam is directed perpendicular to the line of the islands. This is especially true when the islands are closely spaced, since the spreading that results from the width of the radar beam causes the echoes to blend into continuous lines. However, when the chain of islands is viewed lengthwise, or obliquely, each island may produce a separate pip. Surf breaking on a reef around an atoll often may produce a ragged, variable line of echoes.

Submerged objects do not produce radar echoes. If one or two rocks project above the surface of the water, or if waves are breaking over the reef, it may show on the radar. When the object is entirely submerged and the sea is smooth over it, no indication will be seen on the radar. However, in one case a totally submerged reef was definitely detected by a P-band radar. This is theoretically possible for P band frequencies if the reef were submerged in fresh water, but an S-band radar was unable to detect the reef at all. Such an occurrence is very rare.

If the land rises in a gradual, regular manner from the shore line, no part of the terrain will produce an echo that is stronger than the echo from any other part. Consequently, a general haze of signals will show on the indicator and it will be very difficult to determine the range to any particular part of the land. As a matter of fact, while the antenna is held

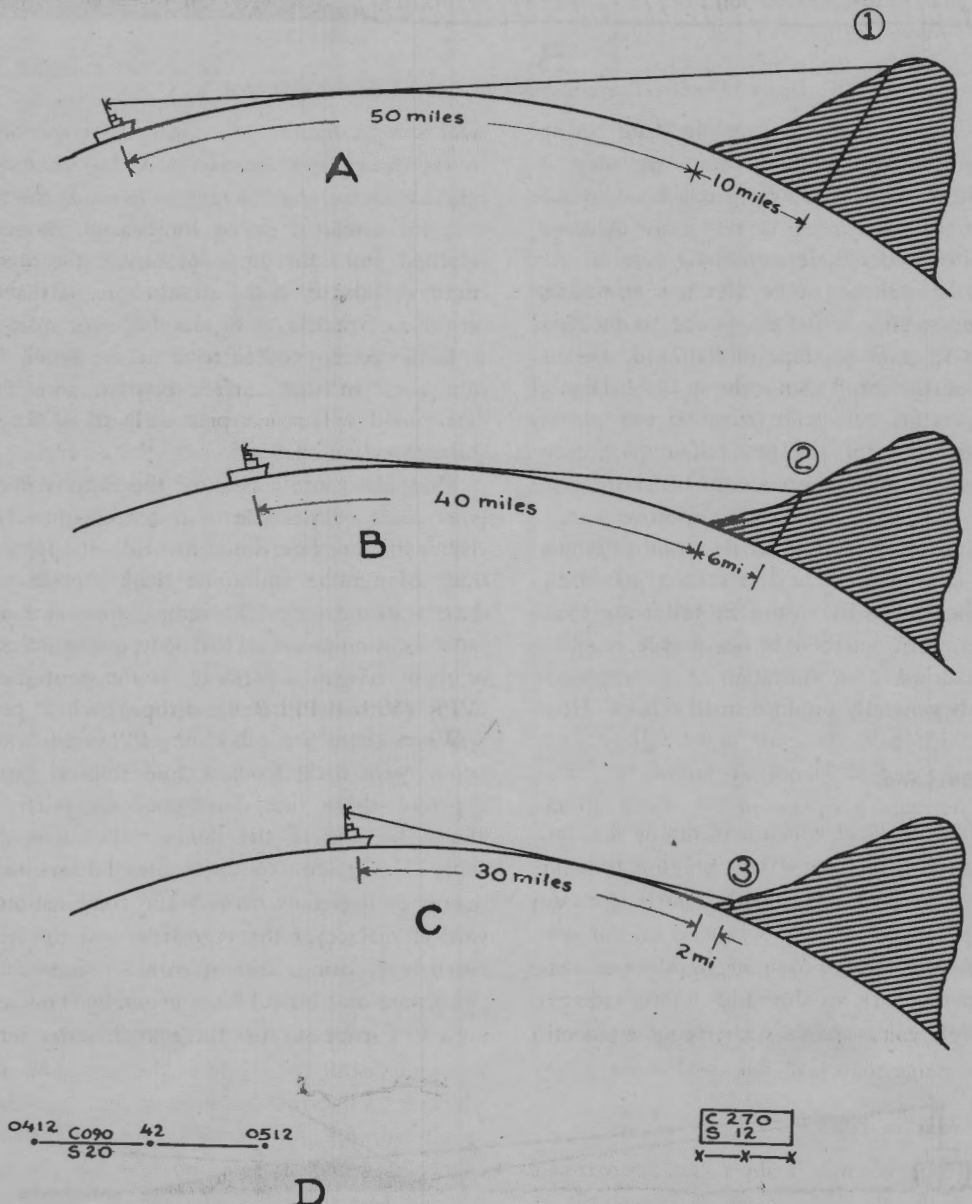


Figure 139—Ship approaching land that rises gradually back of shore.

still and the ship is not rolling, the apparent range to a shore of this sort may vary as much as 1,000 yards. This variation may be caused by slight changes in propagation conditions that cause the beam to be moved up and down the slope.

When a ship approaches or goes away from a shore behind which the land rises gradually, a plot of the ranges and bearings to the land may show an apparent course and speed of the landfall. The reason that the land contact may show a course and speed may be explained by reference to figure 139. In *A* the ship is 50 miles from the shore line, but since the radar beam strikes at point ①, well up on the slope, the indicated range is 60 miles. At some later time, when the ship has moved 10 miles closer to land, the indicated range is 46 miles because the radar echo is now returned from point ②. In *C*, when the ship has moved another 10 miles, the radar beam strikes even lower on the slope, so that the indicated range may be 32 miles. If these ranges are plotted, the land will appear to be coming toward the ship at a speed of 12 knots, as shown in *D*.

In the illustration a smooth gradual slope was assumed, so that a consistent plot was obtained. However, in practice, the slope of the ground usually will be irregular and the plot will be erratic, making it difficult to assign any definite speed to the land contact. The steeper the slope of the land, the less will be its apparent speed. Since the slope of the land does not always fall off in the direction from which the ship approaches, the apparent course of the contact need not always be the reciprocal of the course of the ship, as assumed in this simple illustration.

Blotchy signals are returned from hilly ground because the crest of each hill returns a good echo while the valley beyond is in a shadow. If high gain is used, the pattern may become solid except for the very deep shadows.

Low islands generally produce small echoes. However, when thick palm trees or other foliage grow on the island, strong echoes are often produced because the horizontal surface of the water around the island forms a sort of corner reflector with the vertical surfaces of the trees. As a result, wooded islands can be detected at a much greater range than barren islands.

In general, the echo produced by land will be strong if the land is high and if it rises steeply. Therefore, high volcanic peaks can be detected at a much greater range than low, flat coral atolls.

5. Use of Radar in Piloting.

The PPI scope often can show the approximate shore line clearly. In some cases, it is possible to match the indicator with a chart of the proper scale as a means of determining the position of the ship. If no map is available, or if there is no reliable information about the configuration of the land, it is not possible to identify signals as certainly due to specific features of the shore. The operator cannot tell, from the indicator alone, that one signal comes from a ship, another from a rock, a group of signals from a group of small islands, or a solid block of signals from a mountain. The signal pattern from a group of small islands or rocks several hundred yards apart may simulate the appearance of a convoy of ships, and vice versa. An irregularly hilly shoreline with stretches of low beach between the hills may look on the indicator like a string of separated islands. A blank in the signal pattern may represent a body of water, but it may also represent simply a valley that is shadowed from the radar beam by higher land in the foreground.

The PPI pattern is a map presentation, but it is not a complete map. Even with the receiver gain turned up full, the shore line can show only if the radar beam reaches it. If it is so low as to be hidden by the earth's curvature, or if it is shadowed by higher headlands in the foreground, no energy can reach it and therefore none can be returned to produce signals on the indicator. Signals should not even be expected to appear from all over the land surface that is exposed to the radar beam. The configuration of that surface may be such that some parts of it will reflect practically all of the pulse off in a direction that will miss the antenna.

When a reliable map of the area is available, it will often be possible to match the pattern on the PPI with the shore line on the chart. However, this may be a rather slow and tedious process in many cases. Two devices have been developed which facilitate the comparison of the PPI picture of a shore line with a navigational chart. The first of these is the VPR (Virtual PPI Reflectoscope), which permits the radar operator to see both the PPI screen and a chart superimposed. The superimposition is accomplished by the use of a special transparent mirror through which the operator can see the PPI screen, while a virtual image of a chart is reflected into his field of vision by the mirror. The NMP (Navigational Microfilm Projector) operates on the same principle, but instead of using paper charts, a microfilm chart is projected onto the transparent mirror.

The limitations of range and bearing resolution tend to distort the shape of the coast line, making it difficult to match shore lines accurately without thorough training. For example, the coast line shown in figure 131 when seen on the SK is apparently shaped like the outer blind-zone boundary. Notice that the cove on the left will not show at all since

echoes from the shore extend over a great enough area to conceal it. The same illustration shows that as the bearing resolution of the radar is increased, the apparent shape of the shore on the indicator pattern is more nearly a true indication of the actual shape of the shore line.

Most navigational charts do not show the contours of the land back of the shore, so that special charts will have to be provided for use with both the VPR and the NMP. Even when the contours are shown, it is still not at once apparent just which parts of the shore line will return echoes and which parts will not. In many cases, for example, high land back from the beach will produce an apparent shore line that will not register with the charted shore. Other factors that may produce a false shore line on the PPI indicators are:

(*a*) Numerous off-shore rocks or very small islands may produce merging echoes.

(*b*) Very heavy surf breaking over a reef or sand bar.

(*c*) A row of pilings off shore.

(*d*) Many small boats off shore may produce merging echoes.

(*e*) A row of sand dunes back of a low shore line.

The appearance of a shoreline on a PPI will vary when viewed from different directions. For example, the smooth line in figure 140 represents a charted shore line. The PPI pattern shown in *A* is unlike that in *B* because the radar shadows cast by high ground are different, and because the width of the antenna beam causes different distortion at the two positions of the radar.

The position of a ship can be determined within 100 to 200 yards by the use of either the VPR or the NMP when the vessel is within 10,000 yards of the shoreline. At greater ranges, the accuracy is less, but the necessary precision is also reduced. The accuracy of this aid to radar scope interpretation depends on several factors. Prominent among these factors are such things as the accuracy with which the chart is prepared, the range scale used on the radar indicator, the range and bearing resolution of the set, and the accuracy of ranging with the radar. This last factor includes not only the limitations on range measurement inherent in the equipment, but also the precision with which the set is adjusted and the skill of the operator in matching the pattern and in reading the ranges. The accuracy of VPR or NMP radar fixes also varies with the character of the shoreline. When the shoreline has a distinctive form that is capable of a precise match, as a steep, vertical cliff that falls down to the water's edge, the position of the ship may be rather quickly determined within the limits of ranging accuracy of the radar. However, when the shore is low and featureless and there is no reliable information available of the inland topography, an exact match is very difficult to make, and the position of the ship is correspondingly determined with less certainty.

Figure 140—Shore line on PPI viewed from different angles.

The chief advantage of either of these auxiliary pieces of equipment is in the speed with which the fix can be obtained. They do not make the radar any more accurate, nor do they do anything that cannot be done by other, slower means. However, they should prove of great value in all classes of ships in expediting radar piloting, especially in small vessels that do not have the full CIC facilities available to the larger naval vessels.

In piloting a ship, tangent bearings to a piece of land are often taken as a means of finding the position

of the ship relative to the land. In cases where it is not possible to identify particular features of the land mass on the radar screen, it is not possible to get a fix using radar range and bearing. In such cases, tangent bearings can be measured by radar and a position obtained. However, since the width of the radar beam causes the echo from any point to appear as an arc, each tangent bearing determined by radar must be corrected by approximately half the beam angle. If this correction is not applied, the plotted position of the ship will be much closer to the land than is actually the case.

It is possible to predict the appearance of the PPI screen from charts, but this is a rather tedious process. As an aid in briefing units for missions in which radar is to be used, the RPD (Radar Planning Device) may be very useful. In this device a topographical model is made of the area to be attacked. A special light projector may be put at any desired point on the model and the light beam rotated to simulate antenna rotation. A photograph is taken from a point directly over the light source as the beam rotates, and only the surfaces that are illuminated—which are the surfaces that produce radar echoes—appear on the film. A series of these photographs, suitably printed, will show the operator what to expect on his screen as he approaches a target area.

The RPD, or some other device that allows the appearance of the radar screen to be predicted readily, will be of considerable value in conducting shore bombardments. By this means, it is possible to predict a good reference point for offset firing. The operators of the fire control radar are then able to study the predicted scope patterns before the action so that the bombardment can be carried out more effectively. For example, a cantilever pier on the island of Nauru was predicted as a good offset-fire reference point by study of charts and reconnaissance photographs, although no RPD photographs were made in this case. When the actual bombardment was carried out, it was found that the cantilever pier showed clearly, allowing the position of the ship relative to the target area to be established accurately.

RPD photographs are fairly good approximations to what the radar pattern will look like at a particular place. However, it must be remembered that they are approximations only. The light beam used in producing these pictures does not act in the same way that the radar beam does in that it is not attenuated by the same law. At present, there is no way of producing an RPD photograph that will simulate the appearance of the indicator screen at low gain, which limits the use of these photographs to some extent. For example, the VPR requires low gain for best results, so that best matching cannot be done from an RPD photograph which represents high gain conditions. Also, a single photograph is good for only a single point in the approach to a particular shore. Thus, if a whole approach is to be covered by RPD predictions, a large file of prints will be needed, and if plans are changed, the file will have to be reshuffled quickly. Consequently, the RPD serves best as a briefing device, and either the VPR or the NMP as an aid to piloting in conjunction with a specially prepared map.

In general, it is very difficult, if not impossible, to select particular targets on land by means of radar. When the terrain is hilly, the echo is usually not well enough defined to permit recognizing detailed features of the land. However, if there are large steel tanks or towers on the land, they produce strong echoes. When the receiver gain is decreased, the operator may be able to see the strong echoes returned by the metal targets against the weak clutter of ground echoes. It is possible for the Shore Fire Control Party to carry ashore a radar beacon to use as a means of identifying their position to the radar. The operation of this equipment is such that the radar must be detuned to show the beacon response, so that the clutter from the land is not apparent on the scope, and the beacon response shows clearly.

D. SPOTTING SHELL SPLASHES

It has been found possible to follow projectiles in flight and to observe the splash thrown up when they hit the water. Since the splash lasts for only three to five seconds, considerable training is required before the operator can range accurately on the point of impact. Large shells throw more water up in the air than small shells. Therefore, the splashes produced by heavy guns can be detected at a greater range than those from light guns. In general, the maximum range at which splashes can be detected compares well with the maximum effective range of the guns producing the splashes.

Radar spotting is practicable up to the ranges indicated in the following table:

Size projectile	Approximate maximum range
Inches	*Yards*
16	30,000
12	25,000
8	20,000
6	16,000
5	15,000

As radar equipment is improved and as the operators gain spotting experience, these values may well be

exceeded. This range is dependent primarily on the size rather than on the type of projectile fired. Armor piercing projectiles do not produce a larger splash at the point of impact than non-explosive practice rounds because, if the shell is detonated, the explosion normally occurs well beyond the point where the shell first hits the water. However, high capacity bombardment projectiles fitted with contact fuses may produce a splash that is larger than normal if the shell is detonated on impact with the water.

It usually is impossible to detect the "splash" of a salvo that hits land. But in one bombardment action where the target area was a cleared space in a wooded section, the flying debris thrown up by the exploding shells produced an echo that was visible because no ground echoes were returned from that range and bearing. However, such a fortunate situation exists rarely. Therefore, reliance for checking the accuracy of gun fire in a radar-controlled bombardment must be put in ranging on an occasional salvo purposely dropped in the water off shore.

When the range is purposely altered to cause a salvo to fall in the water, care must be taken to insure that the salvo will fall far enough off shore for the radar to detect it. If the splash is too close to the beach, the weak echo returned from it will not be visible because of the limits of range and bearing resolution.

Projectiles that hit very close to the target may appear to be on because of the limitations in resolution inherent in radar. Therefore, although the shells are followed toward the target on the radar, the absence of splash echoes is not an absolute indication of a hit. In general, projectiles that fall short are easier to detect than those that fall beyond the target, because the range resolution of the radar coupled with the extent of the target in range combine to produce a dead space beyond the target.

Rapid fire may produce a sort of enlarged grass in the area of the splashes because of the continuous fall of projectiles. With salvo fire, however, each projectile produces a single fuzzy echo of short duration. Therefore, salvo fire is much easier to spot by radar than rapid fire.

Because the separation in range between targets required for range resolution is usually much less than that required for bearing resolution, spotting in range by radar is more effective than spotting in deflection. Unless the bearing resolution of the radar is very good, the operator will not be able to detect shell splashes that are at the correct range, but off in deflection. A radar with excellent bearing resolution, such as the Mark 8, is very effective for spotting in deflection.

Anti-aircraft bursts produce radar echoes much less effectively than splashes in the water. The echo is returned partly from the metal fragments scattered through the burst and partly from the hot ionized gases that are the product of the explosion. As the gases expand, they cool; when the gases cool, they lose their ionization. Since the explosion very quickly scatters the metal fragments over a wide area, and because the gases expand very quickly, an AA burst does not reflect radar pulses for more than a second or two.

Within the short time that the echo is visible it is very difficult to determine the range, bearing and altitude of an AA burst relative to the plane at which the shell was fired. A range spot can sometimes be determined satisfactorily on AA bursts. However, the time is so short that it is unlikely that reliable bearing and altitude spots can be obtained unless the operators are exceptionally alert and well trained.

CHAPTER VII

LIMITATIONS IMPOSED ON RADAR BY ENEMY COUNTERMEASURES

A. Introduction — definition of terms.

B. Interception:

Methods employed by the enemy; information gained; measures for limiting interception.

C. Jamming:

Introduction; general effects of jamming on radar operation; electronic jamming; mechanical jamming; anti-jamming measures.

D. Deception:

Methods of radar deception; uses of deception; detection of deception.

E. Evasion.

A. INTRODUCTION

The United States at present enjoys a considerable advantage over the Japanese in the superiority of its radar. To nullify this advantage, the Japanese are producing radars of their own, and at the same time, they are devising ways of decreasing the effectiveness of our radar. Consequently, more and more countermeasures activities should be expected as the Japanese continue to determine the characteristics of American radar, and develop improved countermeasures techniques. This should be especially true when the war is carried close to the islands of Japan.

The following definitions are stated to aid in drawing distinctions among the several allied fields of countermeasures:

Countermeasures are the means employed by the enemy to obtain information about our forces from our use of radar, and to prevent us from obtaining any accurate or useful information about enemy forces through the use of our radar. Countermeasures methods are of four types: interception, jamming, deception, and evasion. The techniques and equipment used to combat jamming are not considered to be a part of countermeasures, since they are, strictly, counter-countermeasures.

Interception is the detection of radar signals by the use of a special receiver. By this means, the enemy learns of our presence in his vicinity, obtains an approximate bearing on our position, and he may determine some of the characteristics of our radar.

Jamming is the deliberate production by the enemy of strong signals for the purpose of hiding his movements or position from our radar by obliterating or confusing the echoes on our indicators. The jamming signals may be produced by a modulated radio transmission, which is electronic jamming; or by echoes returned from many small metallic reflectors, termed Window.

Deception is the deliberate production by the enemy of false or misleading echoes on our radar by the radiation of spurious signals synchronized to the radar, or by the reradiation of radar pulses from extraneous reflectors. Small targets may be made to appear like large ones or echoes may be made to appear where no genuine target exists.

Evasion consists of tactics that are designed to take advantage of the limitations of radar to prevent or postpone radar detection, or to avoid revealing the true position of an attacking force. If attacking planes take evasive action, it may be impossible to determine the height at which they are flying, or the planes may be detected too late for an adequate defense to be made ready.

Interference is caused by the reception of confusing signals accidentally produced by the effects of either friendly or enemy electrical apparatus and machinery, or by atmospheric phenomena. Interference should not be confused with enemy countermeasures.

Anti-jamming, often abbreviated as AJ, is the art of minimizing the effect of enemy countermeasures in order to permit the echoes from targets detected by the radar to be visible on the indicator.

It is important to recognize that the countermeasures that can be used by the Japanese against our radars can also be used by us against their radars. In the same way, the means at our disposal for lessening the effect of Japanese countermeasures are approximately the same as those available to them. Therefore, practice in using and defeating countermeasures of our own devising against our own radar provides excellent training against the radar countermeasures that the enemy may employ. However, a very realistic approach must be made to training of this sort, and the enemy's probable line of thought must be approximated as closely as possible in devising training exercises.

B. INTERCEPTION

1. Methods Employed by the Enemy.

In the early stages of the war the Japanese had only a few types of radar and few installations in

service. As a result, they were not faced with the difficult problem of eliminating interference from a large number of their own radars while they searched for our radar signals with intercept receivers. It is known that the Japs have intercept receivers in use for listening to our P-band radar. It is likely that they now have or soon will have equipment that will intercept our L and S-band radars. In fact, the receiver of the S-band radar with which some of their ships are equipped can be used for limited intercept work. As the war progresses, their intercept receivers are improving.

Several instances have shown that the Japanese sometimes depend on their intercept receivers for early warning of the approach of American vessels. Thus, they may not even turn on their own radars until alerted by the interception of American radar signals. Because of their early start in this field, the Japanese are probably more adept in interception than in any other countermeasures method.

The Germans have developed intercept receivers capable of detecting all our radar frequencies. German submarines therefore have often been able to escape detection by airborne radar through the use of the information obtained by interception.

2. Information Gained Through Interception.

The strength of a radar pulse decreases as the pulse travels away from the antenna. The small part of the pulse that is reflected from a target also falls off in strength as it returns to the radar. Since interception requires only one-way transmission of the pulse, the radar can always be heard at a range greater than that from which useful echoes are returned. For example, the SD radar can detect a large high-flying airplane at a maximum range of 30,000 to 35,000 yards under favorable conditions, but under the same conditions, the pulses can be detected beyond 45,000 yards by an intercept receiver carried in an airplane. A radar receiver, which is more sensitive than an intercept receiver, can detect an SD out to perhaps 75,000 yards if the radar frequency is accurately known and the receiver pretuned to this frequency. Normal interception range should be somewhat less than twice the normal maximum radar range when the intercept receiver is carried in a plane. If the intercept receiver is on a ship or on land, the range of interception can be only a little greater than radar range because of horizon limitations.

One type of information, then, that can be gained from the use of intercept receivers is early warning of the approach of radar-equipped vessels. It may be possible to make a rough estimate of the size of the approaching force my observing the number of signals intercepted.

If the intercept receiver is calibrated, the frequency of the enemy radar can be determined. Other characteristics of the radar can be found by the use of auxiliary equipment with the intercept receiver. Some intercept receivers for the S and X bands are capable of giving only early warning, since they produce an output for a wide band of frequencies without being able to be tuned to a single frequency.

The coverage of a radar installation can be determined by the use of an intercept receiver if the enemy operator is unwittingly cooperative. For example, a fairly complete coverage diagram of a Japanese radar installation was obtained on a radar reconnaissance flight because the radar operator stopped his antenna on the plane each time it appeared. By making many approaches from different directions and at different altitudes, the operator of the intercept receiver was able to plot the whole coverage of the radar simply by noting the point at which the radar beam stopped sweeping to searchlight the approaching reconnaissance plane.

3. Measures for Limiting Interception.

The most obvious way of preventing interception of radar signals is to turn off the equipment. However, the use of radar silence is practical only when the tactical advantage of depriving the enemy of intercept information is greater than that to be gained by radar operation. Any condition of radar silence put in effect must apply also to IFF and VHF communications. The imposition of radar silence for long periods of time may result in a great decrease in the efficiency of the radar operators because they are denied practice.

It is possible for radar pulses to extend below the radar horizon to some extent as a result of diffraction. The diffracted energy usually is so weak that usable echoes cannot be returned from targets in this region. However, intercept receivers on the targets may be able to detect the radar pulses in the diffraction zone, even though the intercept antenna is well below the radar line of sight. If the weather conditions are such as to produce trapping of the radar signals, it will be possible for an intercept receiver within the duct to detect the radar far beyond the normal intercept range. The decision to use radar silence, then, should be based in part on the best available evaluation of the trapping conditions.

Training of operators should be aimed at developing the habit of keeping the antenna in constant rotation. If the antenna is stopped to investigate each target that is detected, an enemy with an intercept receiver may be able to determine the coverage of the radar.

There is a possibility that enemy interception may be delayed by intermittent operation of the radar. If both the radar antenna and the intercept receiver

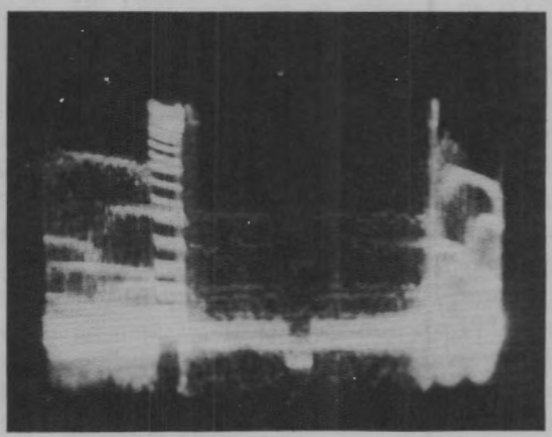
antenna are rotating, there is a good chance that they may not be pointed at each other at the same time. In addition, if the radar is turned off part of the time, the likelihood of the intercept receiver missing the radar will be increased. However, intermittent operation of radar cannot prevent interception; it can only defer it.

As a means of increasing the difficulty of interception, some of the new radars are being fitted with facilities for automatic intermittent pulsing. An extension of this same principle has developed into what is called jitter pulsing, in which the repetition rate of the radar is made random. When the enemy intercepts a radar that is jitter pulsed, he can hear only noise, very much like the noise that he would detect at high gain with no incoming radar signals. It has been shown in tests that jitter pulsing reduces considerably the maximum range of interception.

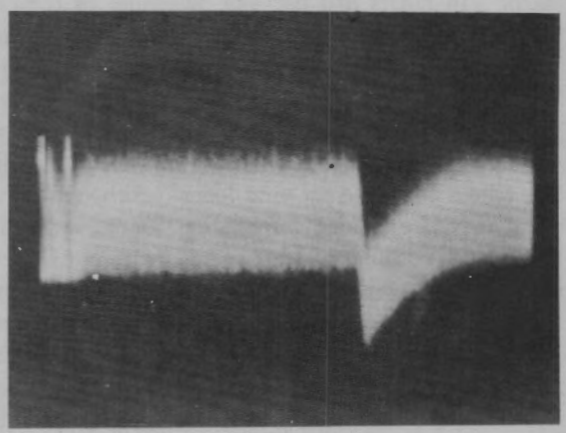
C. JAMMING

1. Introduction.

The effect of radar jamming is to produce a confusing pattern, on the screen of the radar indicator. The single trace that normally appears may become a network of interlaced lines, a solid pattern of light, very strong grass, or the trace may be wiped clean

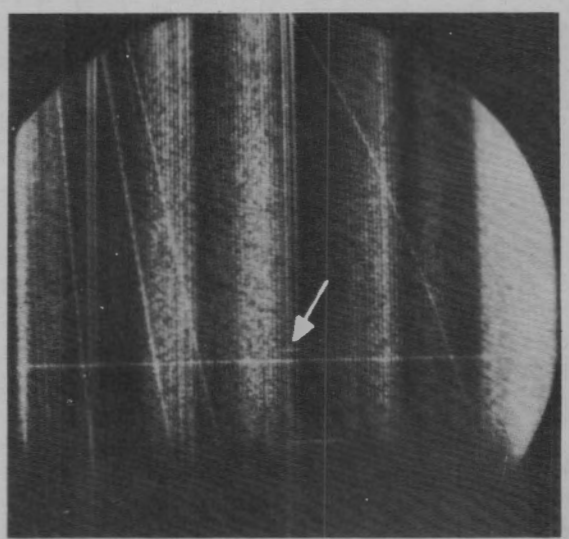


A. Mark 4 radar indicator with off-target jamming modulated with low frequency.



B. Strong noise jamming on SG A scope. Note targets that remain visible at short range.

C. Strong noise jamming on PPI. Note pick-up in side and back lobes. Spiral lines are due to interference from other radar.



D. Mark 8 B scope partially jammed with noise modulated jamming. Note echo still visible at arrow.

Figure 141—Jamming on radar indicators.

of all signals. Variations of these patterns may be produced by changing the amount of and type of jamming, so that an almost infinite variety is possible. Figure 141 shows a few patterns that may be produced on radar indicators by some common forms of jamming. Additional pictures of jamming and operating instructions for combating jamming are presented in part 3 of RADTHREE.

There are two general types of jamming—electronic and mechanical. Electronic jamming is accomplished by the transmission of modulated radio signals, while mechanical jamming is performed by dispersing in the air many strips of metalized paper, called Window. The chief effect of either type of jamming is to prevent or to make difficult the determination of the range of a target in the jammed sector. In radars that use lobe switching or conical scanning to improve bearing accuracy, jamming can produce rather serious bearing errors on the targets that can be seen through the jamming, and the pattern on the scope is often made more complicated by the switching that must be employed to display the echoes from the separate lobes. Although jamming may deny range information to the radar, it usually is possible to determine the approximate bearing from which the jamming comes. Only the approximate position of the enemy can be determined in the presence of jamming, since the only available method may be to employ triangulation using several bearings determined with an accuracy of approximately $\pm$ 3°.

In general, the enemy will derive greatest advantage from jamming fire control radar, especially that used for AA fire control, because this type of jamming will permit attacks by enemy aircraft to be carried out with less likelihood of accurate AA fire. The ability of the operator to interpret the echoes as a means of establishing the size and composition of the targets is always impaired by jamming, and often interpretation will be impossible. The accuracy of the data obtained in the presence of jamming is less than that obtained in normal operation. Jamming usually can be detected on the radar at a greater range than is obtainable on the jamming vehicle as a target. Therefore, it is unlikely that the enemy will be so helpful as to begin jamming while he is beyond the detection range of an early warning radar.

An indicator on which the echo pips show as bright spots, for example a B or PPI scope, is much more vulnerable to jamming than one on which the echo pip shows as a vertical deflection of a bright trace. This limitation is due primarily to the nature of the cathode-ray tube.

If the signals applied to produce the bright spots are allowed to be of large amplitude, the spot will be badly defocused and the pattern on the screen will therefore be fuzzy and indistinct. As a means of preventing this defocusing, the echo pulses applied to a PPI or a B scope are limited at a level just a little above the receiver noise level. This allows all the signals to be clearly in focus, but it also allows even a small amount of jamming to show with a strength equal to that of the desired signals. A second characteristic of the cathode-ray tubes used for PPI or B-scan presentations is the long persistence of the screen that is required because the echo pips are retraced relatively infrequently. As a result of the long persistence of the screen, both echo and jamming signals linger, and it is impossible to see a pattern in which a slight discontinuity may exist to indicate the presence of an echo.

On an A scope, on the other hand, the screen is of short persistence, and the echoes are retraced many times a second without their amplitude being seriously limited. As a result, the A-scope screen may appear as a jumbled mass of moving lines, but the echo will appear as a discontinuity in the pattern produced. Since the echo is synchronized, it will always appear at the same place on the sweep, while the jamming in general will move across the screen.

One serious result of the limitation of the utility of a PPI scope in the presence of jamming is that the system of repeater plan position indicators will be made ineffective. In order to combat jamming, the antenna of the radar must be stopped on the target, since even the simplest form of jamming produces a bright sector on the PPI and very little can be done to improve the picture if the jamming cannot be removed entirely. With the antenna stopped, very little useful information can be gained from any of the PPI's connected to that radar. The projection PPI, type VG or VG-1, is likely to be even more seriously affected by jamming than the normal equipments because of the very long persistence of the screen. However, the system of repeater PPIs provides the advantage of permitting a rapid check to be made of which radars are being jammed by simply turning the selector switch successively to all radars that can be connected to the indicator.

2. Electronic Jamming.

Electronic jamming is accomplished by transmitting modulated radio waves on a frequency as nearly the same as the radar frequency as possible. All possible types of modulation have been tried, but the most effective jamming is produced by modulating the radio wave with random noise. When such a signal is introduced into a receiver, the detected signal resembles the receiver noise in appearance on the indicator. Since it is impossible to eliminate receiver noise by any known methods, it is also im-

possible to eliminate noise jamming after the signal has entered the receiver because the electrical characteristics of this type of jamming signal are identical with those of receiver noise.

Types of modulation other than noise are less effective for jamming because they can be dealt with more easily. A few of the simpler forms of jamming can be eliminated almost completely by proper adjustment of the anti-jamming circuits, and some degree of readability can be effected against all but strong noise modulation, providing the receiver is not saturated by the jamming.

Off-target jamming can produce bearing inaccuracies up to half the beam width when it affects a lobe-switching radar. Since most fire control radars use lobe switching or conical scanning in an effort to obtain a high degree of training and pointing accuracy, they are very susceptible to bearing and position angle inaccuracies in the presence of jamming.

It is difficult to produce jamming signals that can obscure the echo signals completely if the operator of the jammed radar employs effective AJ measures. The appearance of the indicator can be improved in the face of almost all types of jamming when the operator is skilled. However, if adequate equipment is available to the enemy, and if it is used skillfully, he can jam a radar channel so completely that it will be useless. Fortunately, this seldom occurs in practice. In general, a single electronic jammer can jam effectively only a single radar set, because technical obstacles make it difficult to spread the jamming energy uniformly over a wide frequency band. Therefore, all the SG radars in a task group, for example, probably will not be completely jammed simultaneously unless the enemy employs a large number of jammers, or unless all the SG's in the group are on the same frequency.

Radar depends on two-way transmission. The power of a pulse sent out from the radar toward a high-flying airplane falls off as the square of the distance. The part of the pulse that strikes the target is reflected back toward the radar as an echo. During the reflection time the target is acting as a weak transmitter, and the signal it returns also is attenuated as the square of the distance. The echo signal returned to the radar from the airplane therefore varies inversely as the fourth power of the range. Hence, the radar echo generally is a very weak signal because of the double attenuation encountered.

Jamming is a one-way operation, so that the jamming signal is attenuated proportional only to the *square* of the range. A jammer can have a considerably smaller peak power output than a radar, and yet because of the relatively low attenuation, the jammer can produce in the radar receiver a signal larger than the echo. However, the power output of the jammer is limited because, unlike a radar transmitter that produces a pulsed signal, most jammers must transmit continuously in order that the jamming signals may fill up the entire range of the radar indicator.

The variation in relative echo strength with range is shown by curve 1 in figure 142, and the variation of the relative jamming signal strength in the receiver is shown by curve 2. It can be seen that as the target, which is assumed to carry the jammer, goes away from the radar, echo signal strength

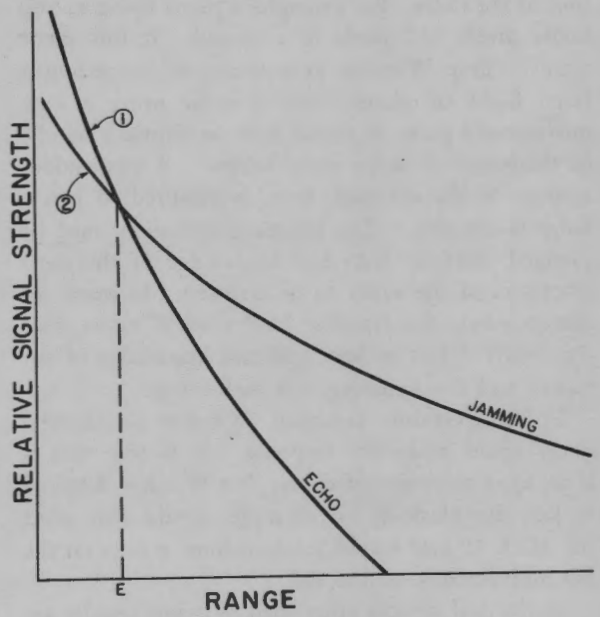


Figure 142—Variation of echo and jamming signals as functions of range.

falls off more rapidly than the jamming. As a result, the effectiveness of the jamming is great at long range. However, at the range indicated as *E* the echo and jamming signals are of the same strength. Closer than this range, the echo rapidly becomes stronger than the jamming signal, and the jamming is ineffective. It is evident that in all cases there is a minimum range within which a target cannot conceal itself by transmitting jamming signals.

3. Mechanical Jamming.

Mechanical jamming is accomplished by dropping thousands of reflecting strips in the area where it is desired to prevent radar ranging. These metal strips, called Window, are designed to be approximately a half wavelength long for the radar frequency to be jammed. They usually are made of very thin aluminum foil backed by light, tough paper. Window most frequently is dropped in bundles from airplanes, but it can be dispersed from shells or

rockets. The strips fall at about 300 feet per minute so that the signals returned from them persist on the jammed radar screen for perhaps 20 or 30 minutes, depending both on the height from which they are dropped and on the extent of the vertical coverage of the radar antenna. The signals returned from the cloud of Window become so scattered after the first 10 minutes that the Window no longer provides strong enough signals for jamming, since echoes from targets can be seen through it.

In order to be effective as a means of jamming, bundles of Window must be dropped within distances comparable to the range and bearing resolution of the radar. For example, a plane flying at 200 knots covers 112 yards in a second. If this plane were to drop Window as a means of concealing a large flight of planes from a radar using a one-microsecond pulse, it would have to release a bundle of thousands of strips every second. A tremendous amount of the material, then, is required to jam a radar thoroughly. The jamming operation must be planned carefully with full knowledge of the characteristics of the radar to be attacked. In many instances where the Japanese have used Window, they apparently did so without sufficient knowledge of our radars and the jamming was ineffective.

Unlike electronic jamming, Window has a relatively broad frequency response. It is true that it is cut for a particular frequency, but Window dropped to jam the Mark 4, for example, would also affect the Mark 12 and would produce some echoes on the SG and perhaps on the SK.

Mechanical devices other than Window usually are used only for deception.

4. Anti-Jamming Measures.

The most vigorous anti-jamming measure is the destruction of the jamming vehicle by direct action. To accomplish this, the jammer must be located by means of triangulation using radar bearings and then attacked by bombing, rockets, shellfire, or whatever means is most applicable.

The bearing of the jammer usually can be found within approximately 3° by maximizing the jamming on the radar indicator. If two or more bearings are taken simultaneously on a sufficiently long base line, the position of the jammer can be found by triangulation. Should the enemy use several jammers spread over a wide front, it will not be possible to obtain an accurate bearing on any single jammer unless the bearing resolution of the set in question is of very high order. Another factor that may complicate the measurement of the jammer's bearing is the reception in the side lobes of the antenna. For the purposes of obtaining bearing, the effect of the side lobes may be considerably reduced by a large reduction of the receiver gain, but for reading through the jamming, the optimum gain setting may be at some other point.

In the event that destruction of the jammer is not practicable, a more passive approach to the problem must be made. Thorough training of operating personnel is the most effective AJ measure that can be taken before enemy jamming is actually encountered.

Because of the difficulty of doing a complete job of jamming, the chief value of jamming is in the element of surprise. For example, on February 12, 1942, the Scharnhorst and Gneisenau passed through the English Channel under cover of the first large-scale use of radar jamming in this war. The ships were not seriously damaged by shore batteries because the jamming created a small panic among the radar operators so that the vessels were not tracked by radar, and they were invisible under the cover of the weather. It was found later that the type of jamming used in that action presented little difficulty to an operator trained in combating jamming. Therefore, the soundest AJ measure that can be taken is the thorough training of the radar operators. When they are completely familiar with appearance of jamming and when they know what to do if it appears, the surprise value of jamming will be negligible.

It is extremely important to recognize the cause of any unusual patterns that appear on the indicator. Jamming, interference, and internal faults in the radar all can cause the indicator presentation to vary from the normal. The operators can be made familiar with many of the common results of failure of the radar by having the technician remove certain of the tubes in the set so that the change in the indicator presentation may be observed. Interference that arises from some source on the same ship can often be recognized because it affects the radar uniformly at all bearings, or by noting the coincidence of the interference with the operation of some other equipment on board. Part of the training of the operator must equip him with knowledge of these effects so that he will be able to distinguish quickly and accurately between jamming and the effects of interference or failure of the radar.

One very common type of interference is that encountered between radars of the same type operating on several ships in company. This interference, which usually produces strong pulses that move across the A scope or spiral lines on the PPI, is seldom severe enough to reduce to any serious extent the effectiveness of the radars involved. Interference on both the SJ and SG radars has been encountered from Japanese shipboard radars, but no serious limitation on the use of the equipment was experienced.

However, the Japanese radars also must have encountered interference, so that there is a possibility that the Japanese soon will attempt to jam some of our S-band radars, although no definite jamming has been reported, as of the end of 1944.

The confusion produced on the indicator by jamming usually is unintelligible to an inexperienced operator. However, after proper training, the operator will be able to read through most varieties of jamming with fair success. The use of special anti-jamming devices facilitates interpreting the indicator presentation; but, even though the AJ devices may be very elaborate, the echoes cannot be made as clear in the presence of jamming as when no jamming signals are received. Training devices have been developed for the purpose of simulating electronic jamming. By use of these trainers the operators can be given constant practice in working through jamming, so that they may become thoroughly experienced in this phase of radar operation. The trainers that are available for simulating radar jamming are: the OAV and OAV-1 for P band; the Mark 100, Mark 101, and Mark 5 for L band; and the AN/UPT-T3 (OBW) for S band. The Mark 6 trainer should replace the other L-band equipment when it becomes available, and a Mark 8 jamming trainer is being produced to enable jamming exercises to be carried out against S-band fire control radar. An attachment for some operational jammers, which is designated RF-9/UPT, is available for use in jamming exercises where it is desired to modulate the jammer with signals other than noise.

The enemy has no means of gaging the effectiveness of his jamming other than by observing the reaction of the radar. If the radar frequency is shifted markedly or if the radar is turned off, the enemy can well presume that his jamming is effective. Therefore, it is desirable to continue to operate the radar, even when the scope is unintelligible, in order to deny the enemy the satisfaction of knowing that his jamming is successful. Continued radar operation also has the effect of immobilizing the enemy jammer on one particular frequency, thereby forcing him to use more jamming equipment if he attempts to jam all our radars. The radar certainly is of no value when it is turned off; when it is on, there exists a possibility that the enemy may close to a range where the jamming is no longer able to obscure the echo from his ship. Since it is difficult to maintain the jamming at full effectiveness over long periods of time, it is well to keep the radar energized to allow the operator to maintain a constant watch on the indicator pattern. Small variations in the frequency transmitted by the radar may combine with variations in the jammer frequency to produce a condition that may permit the operator to obtain some useful information through a momentary gap in the jamming.

It is difficult to jam a centimeter-wave radar at all ranges because reflection of the jamming signals from the water produces many narrow lobes in the vertical coverage pattern of the antenna of the jammer. If the jamming is to be effective, the radar antenna must be kept within one of the lobes of the jammer antenna. This is relatively easy to accomplish at long range, but at short ranges the lowest lobe of the jammer may be below the radar antenna, so that no jamming energy is received by the radar. As the range closes, the radar antenna may again be receiving jamming signals from one of the higher lobes. This effect is not apparent in the radar echoes, since targets, especially ships, are much larger than the antenna alone, and they can therefore reflect energy from several lobes simultaneously. Since it is known that this effect does exist, it is well to keep microwave radars operating in the face of jamming because there may be null zones in the interference pattern of the jammer antenna where the radar operation will be nearly normal.

Since electronic jammers cannot cover a very wide band of frequencies, it is a good AJ measure to deploy the radar frequencies used over as wide a range as possible in order to force the enemy to use a great quantity of equipment if he wants to jam all the radars in a particular force. New radar equipment to be supplied to the Fleet will employ new frequencies as a means of making more difficult the task of jamming all of our radars. Additional flexibility in the form of sets capable of shifting frequency rapidly or of operating on a continuously varying frequency will be supplied in the future. The transmitters will be of higher power, and both the pulse repetition rate and the pulse duration will be variable. All receivers supplied with new types of radar will incorporate the most effective anti-jamming features known. No radar in current use is capable of operating on a constantly changing frequency. This will not be possible until the SR-4 or some radar of similar principle, becomes available to the Fleet, probably in 1946. However, jamming can be avoided, at least temporarily, by changing the radar frequency. Although it is possible to shift the frequency of some of our radars within rather small limits, not every set is capable of such operation. In any case a change of frequency affords only a few minutes' relief against an alert enemy, since equipment is available by the use of which the jammer can follow the radar frequency within a very short time. A slight advantage can be gained by tuning the receiver to the frequency to which it is intended to change before the transmitter is shifted. If the

operators of the enemy jammer are slow, the advantage will be greater.

Since jamming produces on the radar screen many signals in addition to the desired one, the resultant confusion of signals makes it difficult to observe the desired echo. In many cases the jamming and echo signals interact to produce a distinctive break in the jamming pattern. Although this break may not have the appearance of a normal echo, the operator may still be able to get a range on the target. Anti-jamming techniques and devices, then, are aimed at eliminating as much of the jamming signal as possible, and at creating or accentuating the discontinuity in the remaining pattern on the scope.

Improvement of the indicator presentation in the presence of jamming usually can be effected by proper operating technique and the use of such AJ devices as are available. Varying the gain and the local oscillator tuning on the receiver are often helpful in reducing the amount of jamming signal on the screen, or in producing a clear discontinuity in the pattern. If the jammer is off target, a position of the antenna may be found in which the jamming signal can be greatly decreased without losing a large amount of the desired echo signal.

Anti-jamming circuits are now provided in many radar receivers. The most effective of these circuits are filters in either the intermediate-frequency amplifier or the video amplifier, Instantaneous Automatic Volume Control, and Fast Time Constant coupling. Both the use of the circuits and the operating techniques that help to minimize the effect of jamming are discussed in Part 3 of RADTHREE.

Noise jamming is difficult to counter by any of the AJ devices that are currently available because the character of the noise jamming signal is nearly identical with that of the receiver noise, which cannot be eliminated from the radar receiver output. The fact that the noise voltage is entirely random offers some hope of developing an effective anti-jamming device to counter it, for the echo signal is synchronous. However, manipulation of a few of the radar controls may result in improvement of the pattern on the scope. When the jamming signal is strong, the indicator will be covered with grass, and no echoes can be seen. If the radar has a variable transmitted pulse duration, use of the longest pulse may permit some improvement against noise jamming because the receiver is altered so as to pass only a narrow band of frequencies, which may eliminate a part of the jamming signal. On the other hand, if the enemy uses jamming modulated by noise voltage that is limited in amplitude, it may be helpful to use the shortest available transmitted pulse, because the i-f band width is increased. This may cause the jamming to produce an even pattern in which the noise appears like grass that is freshly mown instead of overgrown. It will be much easier to see the discontinuity produced by an echo in the even pattern than in the irregular pattern of jamming. Thus, improvement may be effected against noise jamming either by causing the receiver to pass a very narrow band of frequencies or a very wide band of frequencies. This type of adjustment is at present available in only a few of the newer radars.

The signals returned from Window are real echoes and it is therefore very difficult to produce an effective AJ device that can discriminate between the desired and undesired signals returned. It is very important to realize that Window does not act as a smoke screen; only the echoes from targets within the area infected with Window are concealed. Targets outside the Window area remain visible, and the passage of the radar pulse through the infected zone does not reduce the power of the pulse. The better the range and bearing resolution of the radar the less effective Window will be in jamming the set. Therefore, when radars are available with variable transmitted pulse duration, the shortest pulse will be the most effective against Window. The use of AJ circuits such as Instantaneous Automatic Volume Control (IAVC) and Fast Time Constant video coupling (FTC), as are supplied in new models of radar or in the current change 50 to the SG, is of great help in reducing the effect of Window because these circuits can almost entirely remove echoes that extend over a relatively long range. Thus, IAVC and FTC are effective not only on sea return, clouds, and land echoes, but also on Window. The use of an expanded sweep, when available, is advantageous in combating Window jamming because the Window echoes are spread out on the fast trace, allowing full use to be made of the radar's resolution. If the Window is not sown closely, it may be possible to see targets between the Window return. A radar with a narrow antenna beam is better able to cope with Window jamming than one having a wide beam because the narrow beam provides better bearing resolution.

D. DECEPTION

1. Methods of Radar Deception.

False or misleading radar echoes can be produced in a number of ways, but the problem of making the characteristics of a false echo resemble those of a real echo is a difficult one to surmount. Many deceptive devices reveal themselves as false because they produce echoes that are nearly stationary in space.

Electronic devices have been developed to accomplish several deceptive tasks. For example, a fire con-

trol radar can be made to indicate an incorrect bearing by synchronizing a device with the lobe switching rate in such a way that the signal returned to one lobe is slightly stronger than the normal echo. As a result the radar operator will match pips on a bearing that may be several degrees away from the true target. Although such devices have been made to work in the laboratory, they are not yet practical for operational use. Very highly skilled operators and rather large equipment are required, and the advantage gained is the production of a bearing error equal at the largest to only half the radar beam angle. Another example is a device that transmits several pulses every time the radar pulse strikes the vehicle carrying it. The target then looks like several targets in a column along the line of bearing. The difficulty with such devices is that they are complicated and that identical sets must be used on every radar frequency to produce coherent deception. It is doubtful that electronic deception will be widely used against our radar by the Japs.

If Window is dropped properly it can produce an echo that looks for a time like a large ship, a flight of large planes, or a flight of small planes. Usually it is not practical to attempt to simulate a surface vessel with Window, since the cloud of reflecting strips would disperse too quickly to lead anyone to believe that the echo was returned from a real ship.

Japanese airplanes have dropped several varieties of deceptive devices other than window. For example, they have used some sort of apparatus that produces a fairly realistic echo, except that the speed of this artificial echo is much slower than that of the plane. These echoes are hard to distinguish without plotting, and since this takes time, the deception accomplishes its purpose of confusing AA fire. Little is known about this device because so far none have been recovered or captured. Another type of decoy reflector that the Japanese have used is apparently attached to a hot-air balloon. The reflecting member of this device is so designed that it can return radar echoes in almost any direction, but because of this property an alert operator usually can recognize it as a decoy, for the echoes are more steady than those from a real target. Other varieties of deceptive devices that may be encountered consist of long metallic streamers connected to balloons or to parachutes, or of floating reflectors like spar buoys, designed to appear like submarine periscopes. The variety of deceptive devices is limited only by the ingenuity of the enemy.

2. Uses of Deception.

The enemy has used deception for several purposes in the past, and as he learns more about our radar, it is to be expected that he will be able to devise new deception methods. In every case, the enemy's purpose is to introduce misinformation on our radar screens as a means of causing nuisance alerts, or in the hope of creating a local superiority for his forces.

By dropping Window, a few planes orbiting may simulate realistically many planes gathering for attack because the genuine targets in such an operation do not exhibit large range rates. Thus, Window can be used to conceal the number of planes in a strike, or as a means of creating a feint attack.

In some cases the Japanese have fitted small craft, such as sampans, with reflecting material in order that the small vessel may return an echo like that from a large ship. The additional reflecting material is much like the screening erected on target rafts used in radar-controlled firing practices. The sampans may then be deployed in a way calculated to reduce our local superiority in an impending engagement. A very effective counter to such a deceptive measure is thorough aerial reconnaissance.

Submarines as well as airplanes can release decoys. One device used by the Germans consists of a balloon tied to a sea anchor by a light wire or cord from which are streamed several long strips of aluminum foil. This device returns an echo that closely resembles the echo from a submarine periscope in both size and character. The deception provided by this device is in general excellent, although not equally good on radars of different frequencies. The echo returned from a decoy of this sort can usually be revealed as false by comparing the plotted track with the speed and direction of the surface wind. Because of the sea anchor the speed of the decoy will be less than that of the wind, but the course must agree with the wind direction.

In most cases the speed of such a decoy is a reasonable speed for a submarine, so that when the track of an object that appears to be a submarine is found to agree closely with the wind velocity, the target must be regarded with suspicion. The uses to which such a clever decoy can be put are numerous. For example, it has been used successfully as a lure to bring a destroyer into position for torpedo attack by the real submarine which lay in wait close by the decoy. In at least one case we lost a destroyer because of the German use of this type of decoy.

Another type of false reflector that is released from submarines is a sort of spar buoy which resembles a periscope. Deceptive devices of this sort are effective primarily against airborne search radar, although they may also be effective decoys against surface search radar. These devices apparently are fitted with a charge that will sink them several hours after their release.

3. Detection of Deceptive Countermeasures.

Since it is difficult to make false targets return signals that are in all respects the same as the echoes returned from genuine targets, careful observation of all echoes will often reveal deceptive countermeasures. It is especially difficult to create adequate deception by electronic means.

Most mechanical reflectors used for deception move in a direction and at a speed that corresponds to the wind velocity. Therefore, plotting the suspected echo and comparing its track with the speed and direction of the wind will often reveal the false character of the contact.

Since it is difficult to make mechanical reflectors that respond equally to all frequencies, comparison of the echo received on several radars of widely different frequency should reveal some enemy attempts at deception. The repeater PPI system will be of great help in making such a comparison, since several radars can be connected to a single PPI by means of the selector switch.

Deceptive devices cleverly used with a reasonably full knowledge of our radar may often be highly effective. In general, however, careful scrutiny of echoes will enable an experienced operator to distinguish between the real and the false echoes. If jamming is used, even in small amounts that are insufficient to be effective alone, the clutter produced on the indicator will prevent the operator from observing the minor variations in the signal that reveal it as false. Therefore, deception used simultaneously with jamming is likely to prove very difficult to counter.

E. EVASION

Enemy planes often take advantage of the limitations of air search radar to avoid detection, and frequently they maneuver violently to avoid being tracked in altitude. However, with the installation of SP radars on many ships and the use of existing SM radars, along with the several members of the SR family which will soon be available, such evasive action will no longer be fully effective.

Because of destructive interference, the signal strength near the water is very small, which causes low-frequency, low-height radars to be unable to detect low targets at long range. Since air search radar antennas do not elevate, they have no position angle resolution. Therefore, planes that attack by flying from over land are often not detected until they are in position to begin attack. Another result of the lack of position angle resolution is the inability of the air search radars to follow changes of altitude. This limitation allows attacks to be made by approaching low and climbing sharply or by approaching in a long glide as ways of delaying interception. The wider use of low-angle search and height-finding radars such as the SM and SP should help to reduce the success of these tactics.

Captured documents indicate that the Japanese are aware of the limitations on the resolution possible with radar and that they have experimented with formations of airplanes arranged to exploit this weakness. If an attacking group of planes is formed so that the interval between planes is less than that required for the radar to resolve the echoes into separate pips, both bearing and position angle data determined by radar may be inexact. Tactics of this sort may be especially useful against anti-aircraft fire control radar because their use may reduce considerably the effectiveness of the fire. This is especially true of the Mark 4 and Mark 12 radars because the lobe switching used causes these sets to have rather poor resolution in both bearing and position angle.

CHAPTER VIII

REPEATER PLAN POSITION INDICATORS

A. Introduction — need for repeaters.

B. Standard repeater PPI:

Function; characteristics; model VC; model VD; model VH; delay box.

C. Precision repeater PPI:

Characteristics; relation between B scope and PPI; operation of precision repeater PPI.

D. Projection PPI:

Characteristics; operation of VG repeater PPI.

E. Off-center PPI:

Advantages; relation to normal PPI.

A. INTRODUCTION

As the great usefulness of radar on board ship became apparent, it was realized that full benefit could not be taken of the information provided by this equipment if only the radar operator could see the indicator. Therefore, repeater indicators were produced so that radar information could be made readily available at many positions in the ship remote from the radar console. The use of repeater indicators permits great flexibility in radar operation. For example, the range scale on a repeater indicator can be selected for whatever application the repeater is to be used, independently of the range scale in use on the master indicator. Large repeater plan position indicators have been developed with which it is possible to keep directly on the face of the PPI a summary plot of all detectable targets. Methods of improving the display of radar information are under study in order to make the repeater PPI more useful. Smaller repeater plan position indicators are available for use in positions where it is necessary to keep track of every target.

B. STANDARD REPEATER PPI

1. General

The function of a standard repeater plan position indicator is to duplicate the information shown on the master PPI to which the repeater is connected. At present, the repeater presentation may differ from the master only in the size of the cathode-ray tube and the sweep length used, although modifications will probably soon be available to increase the usefulness of the repeaters.

Standard repeater PPIs do not have facilities for the generation of a range ring incorporated in their circuits; the ranges of targets can only be estimated by reference to range markers. Therefore, the accuracy of range determination is not of high order, and it is dependent on the range scale used. If the range of a target can be estimated within 2% of the length of the range scale in use, then the accuracy expressed in yards will be poorer the longer the range scale is. For example, on a 10-mile scale (20,000 yards), range can be estimated within $\pm$400 yards, but on an 80-mile scale (160,000 yards) ranges can be estimated within only $\pm$1,600 yards.

The resolution of a repeater PPI is controlled primarily by the characteristics of the radar to which the repeater is connected, but the range scale used may also affect range resolution to some extent. Thus, a short range scale on the repeater PPI will provide better resolution of near targets than is possible on the master PPI if a long range scale is used for some reason on the master. However, if both indicators are on the same range scale, the resolution should be nearly the same for both. Bearing resolution cannot be improved by the use of a repeater PPI, since this characteristic is controlled primarily by the beam width of the radar antenna.

2. Model VC and VC-1 RPPI.

Since the VC type of repeater PPI is not of splashproof construction, it can be used only in protected locations. The early models were provided with 7-inch cathode-ray tubes, but some of these equipments subsequently have been modified to accommodate a 12-inch tube. The range rings on the VC and VC-1 are scribed on a plastic overlay rather than their being produced electronically. These range marker rings can be calibrated by comparison with the range marks produced by the master PPI. The range scales used on the VC and VC-1 are 20, 75, and 200 nautical miles. In general, the VC and VC-1 are very similar to the master PPI of the SC-2 and SK radars.

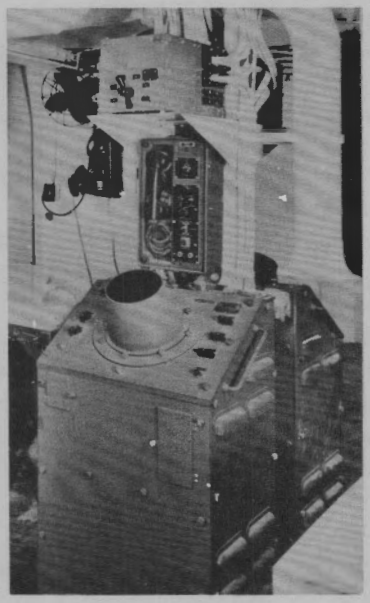
3. Model VD, VD-1, and VD-2 RPPI.

The VD type of repeater PPI is of splashproof construction, so that it can be installed in locations exposed to the weather. The cathode-ray tube is

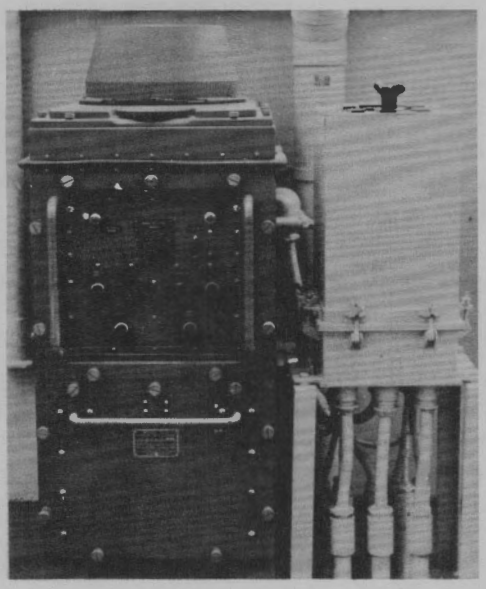
seven inches in diameter, mounted with the screen horizontal. Range rings are produced electronically to serve as an aid in estimating the ranges of targets. Most of the VD, VD-1 and VD-2 repeater PPIs employ the standardized range scales of 4, 10, 20, 80, and 200 nautical miles. The 10-mile scale was not included in the first 50 VDs that were produced.

4. Model VH RPPI.

The VH type of repeater PPI is built in two units so that the cathode-ray tube can be put in restricted spaces or exposed locations where other types of repeaters would not fit. A five-inch cathode-ray tube is contained in a small waterproof case approximately 7 inches wide, 9 inches deep and 18 inches high.



A. Model VC repeater PPI.



B. Model VD repeater PPI.

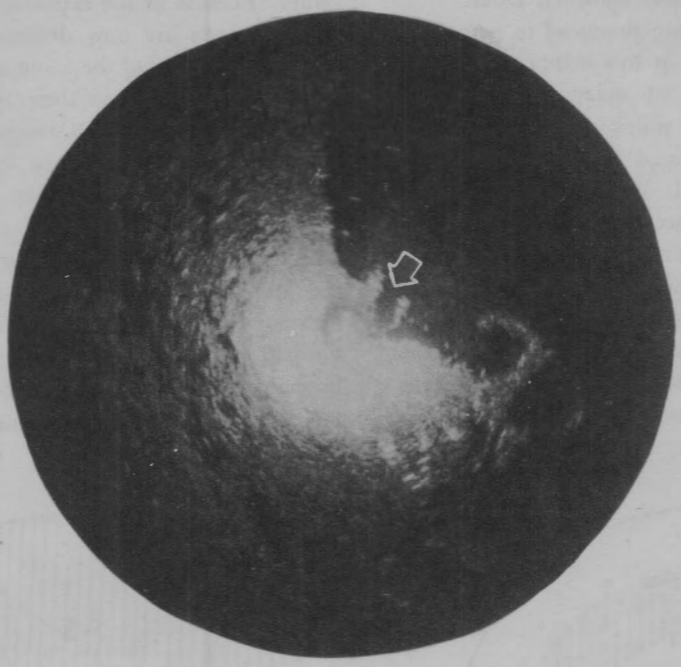
Figure 143—Standard repeater PPIs.

The driver unit, in which most of the electronic circuits are located, is contained in a separate case that may be located as far as 50 feet away from the cathode-ray tube unit. The range scales to be provided with the VH are 2, 4, 10, 20, 80, and 200 nautical miles. Another repeater PPI unit, which is very similar to the VH in form except that it uses a 12-inch cathode-ray tube, is currently under procurement. This unit is to be called the VJ.

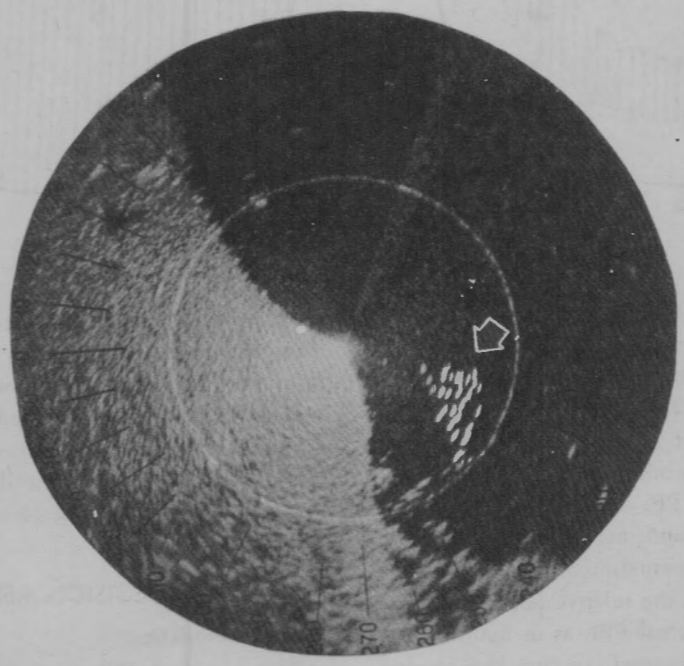
5. Delay Box.

The range resolution of which a PPI is capable on long range scales is relatively poor. This failing is caused by the limitation on the minimum spot size that can be produced on the screen of the cathode-ray tube. For example, on a 12-inch tube one microsecond occupies only 0.0025 inch of the 200-mile range scale, while the minimum possible spot of light that can be produced on the screen may be approximately 0.03 inch in diameter. Under these conditions, even a 1-microsecond pulse would appear to be a mile wide, so that the PPI is far from able to display the resolution of which the radar is capable. On a shorter range scale, such as the 10-mile range, for example, the spot size is small enough in terms of yards that it does not limit the resolving power of the PPI, and the range resolution is greatly improved. Therefore, if it were possible to delay the start of the sweep for a time equivalent to 50 miles, for example, targets at 56 miles could be viewed on the 10-mile scale with good resolution, instead of on the 80- or 200-mile scale with relatively poor resolution.

Normally the sweep on any indicator is made to start as nearly as possible at exactly the instant that the radar transmits a pulse. If the trigger pulse that is used to start the sweep is delayed, the sweep will start at some time later than the instant at which the transmitted pulse is sent out. Thus, if a sweep normally starts at zero and extends to 10 miles, it will start at 50 miles and sweep to 60 miles if the sweep trigger is delayed a time equivalent to a range of 50 miles. This process, then, expands the presentation of a part of the area covered by the radar. Figure 144 shows an illustration of the increased resolution provided by a delayed PPI. In *A* the 100-mile sweep shows a convoy in Massachusetts Bay, indicated by the arrow. Very little information can be gained from this presentation except the knowledge that many ships have been detected. The expansion of the ring on the main PPI between 20 and 40 miles is shown in *B*. Notice that the single ships of the convoy are shown clearly because of the greater



A. Airborne PPI on 100-mile range scale taken at 5000 feet. Arrow points to convoy in Massachusetts Bay.



B. Delayed PPI in same plane. Sweep starts at 20 miles and extends to 40 miles. Note increased resolution on convoy shown in A.

Figure 144—Normal and delayed PPI.

resolution possible on the 20-mile range scale. These pictures were taken on a developmental radar.

The device which is being produced to permit the use of repeater indicators in this manner is called a delay box. The amount of delay is continuously variable from zero to 180 miles, and the amount of delay to be used is indicated by a range ring that appears on the normal PPI. When the repeater indicator is switched to produce the expanded presentation, this indicating range ring collapses to a spot at the center of the screen, while at the same time the sweep length is changed to the range scale selected to provide the desired degree of expansion in the area under observation. Since the amount of delay introduced by the Delay Box is indicated directly by the outer edge, and *W* and *Y* midway out from the center. Because of the expansion, the bearings of the several targets are now different. However, both *F* and *Z* are expanded the same amount, since they are at the same range, and their apparent relative position is unchanged. The bearings to targets *W*, *X*, and *Y* on the other hand are considerably changed. Notice that any target at a 40-mile range must bear 210° from *F* because the 40-mile range circle collapses to a point at the center of the scope. Since the amount of distortion is dependent on several factors, it is very difficult to predict. For example, both *W* and *Y* are at the same range but at different bearings. The errors in the bearings to these two targets from *F* are by no means equal.

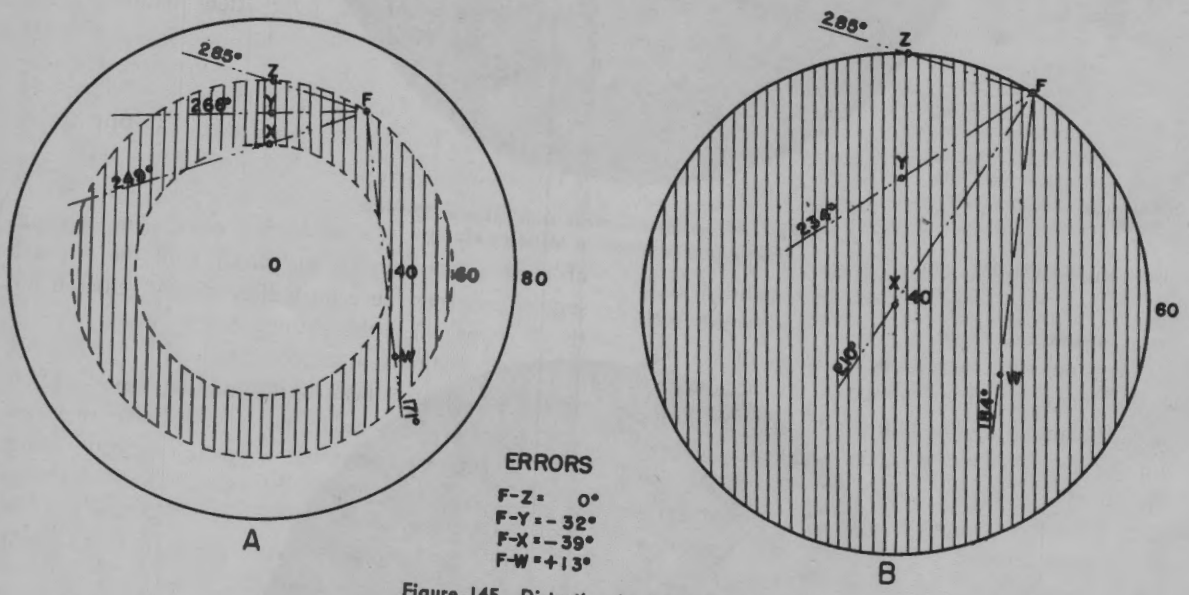


Figure 145—Distortion in delayed PPI.

calibration on the controls, the range of any target can be measured to an accuracy of one per cent by adjusting the delay so that the echo is brought to the center of the delayed PPI presentation. The Delay Box is so designed that it can be applied to any remote repeater plan position indicator.

The use of a delayed PPI will create a new problem for fighter directors and intercept officers because the expansion of the presentation is accompanied by rather great distortion in the relative positions of the several targets. On a normal PPI, as in figure 145A, the presentation is undistorted, so that the bearing of one target from another can be readily estimated from the indicator screen. Thus the operator could find that the bearings of targets *W*, *X*, *Y*, and *Z* from the friendly target at *F* are as indicated on the drawing. However, if the start of the sweep were delayed 40 miles and the 20-mile range scale used, target X would be at the center of the scope, *F* and *Z* at the

However, the range and true bearing of each target from the radar antenna can still be read correctly from the indicator. Therefore, if it is desired to control aircraft from a delayed PPI, the correct bearing of one target from another can be found only by taking the time to plot the data obtained from the indicator. Vectors cannot be taken directly from the delayed PPI.

C. PRECISION REPEATER PPI

1. Characteristics.

The precision PPI is designated VF. This unit displays .radar information on a 5-inch PPI and a 5-inch B scope. The PPI is quite conventional, and the range scales provided are 4, 20, 80 and 200 nautical miles, with four range marker rings produced electronically on each range scale. Thus, range can be estimated directly from the PPI presentation if desired. However, a range unit is also provided for

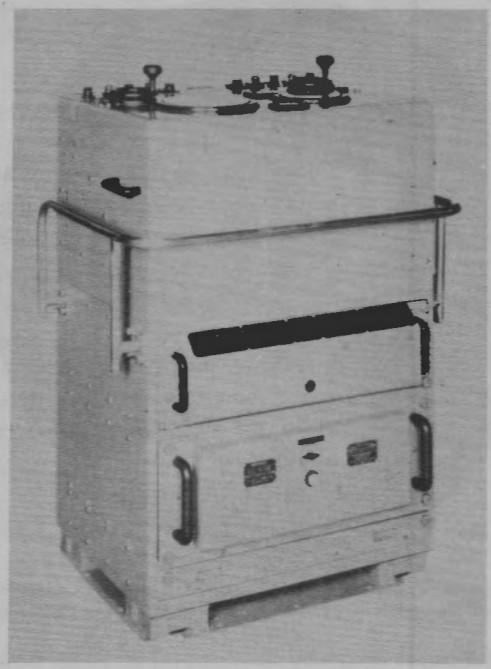


Figure 146—Type VF precision repeater PPI.

precise range measurement on the accompanying B scope. The B scope displays on an expanded scale the echoes selected from a small area on the PPI. The expansion afforded on the B scope makes possible the measurement of range to an accuracy of ± 20 yards, and provides improved range resolution within the area that the B scope can display.

The B-scope sweep is approximately 4,000 yards long, and arranged to show targets 2,000 yards on each side of a selected range. The range unit is so designed that only targets within 20 miles can be displayed on the B scope. The total angular width of the B scope is 30°, so that the area 15° to either side of the cursor on the PPI is shown expanded.

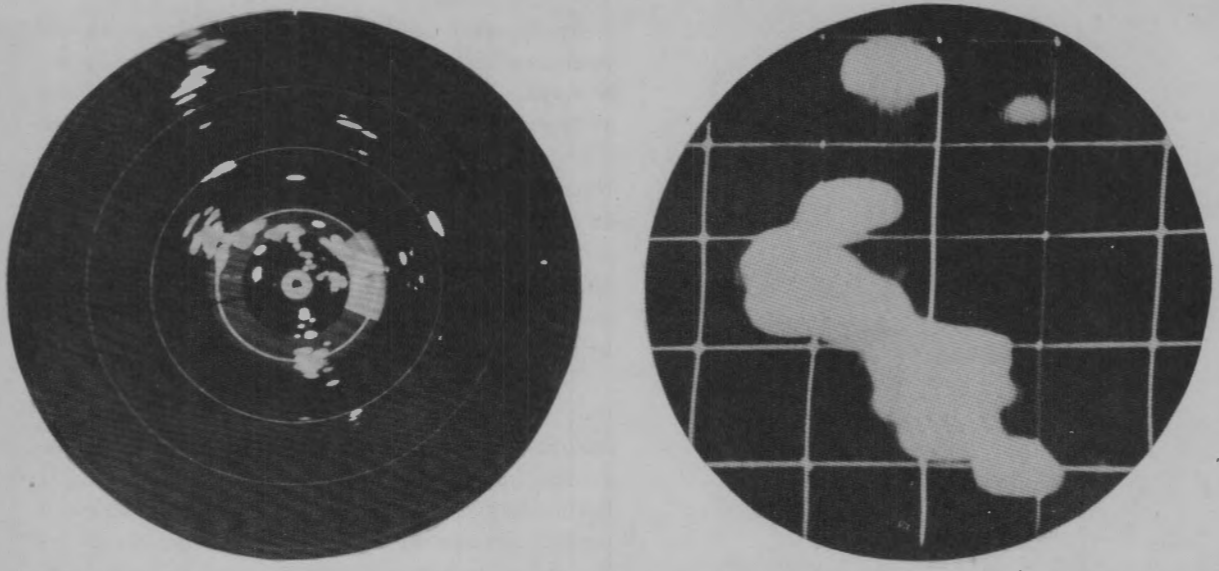
The VF precision PPI incorporates provisions for transmitting both range and relative bearing to remote locations by 1-speed and 36-speed synchros.

2. Relation Between B Scope and PPI.

The area on the PPI which is to be shown expanded on the B scope of the VF is selected by adjustment of a bearing cursor and a ribbon marker on the PPI screen. The bearing cursor is a black line scribed on a plastic overlay. The operator sets the cursor over the desired target, and an area 15° on either side of the cursor is automatically displayed on the B scope each time the PPI trace passes through this sector. The black line in figure 147A, at approximately 085° true, is the cursor, and the center vertical line on the B scope in figure 147B corresponds to this bearing. Since the bearing of the cursor is always represented on the B scope by the center dot, it is apparent that only bearings relative to the cursor can be read directly from the screen of the B scope. The B scope is not stabilized in azimuth, so that true north does not always appear at twelve o'clock as on the PPI. The ribbon marker is the brightened annular segment shown in figure 147A. It is approximately 4,000 yards wide so that it can show on the PPI the range limits of the area that will appear on the B scope. Thus, the actual segment of the PPI selected for enlargement is shown by the intensified area on the PPI screen.

The B-scope pattern is traced once every revolution, during the time that the PPI sweep is traversing the intensified segment. As a result, the B-scope echoes are retraced intermittently only, causing a fast-moving target to seem to move in a series of jumps. Because of the intermittent nature of the B-scope echoes, it is difficult to align the echo with the center range line. Therefore a correction circuit is provided in the VF as an aid to keeping the desired echo centered on the B scope. While the PPI sweep is continuing beyond the intensified segment, the range and bearing knobs can be moved to place a spot directly under the desired echo. The turning of these knobs corrects the position of the selected segment so that the echo will be nearly centered on the B scope when the pattern is retraced.

It was originally intended that the VF would provide more accurate bearing information than could be obtained from the radar itself. To make this improved accuracy possible, a synchro system using both 1-speed and 36-speed elements was provided. However, none of the radars available are capable of supplying antenna train information precisely enough to allow advantage to be taken of the precision built into the VF. As a result, the bearing accuracy obtainable from the VF is little better than that obtained from the radar. Such improvement in accuracy that is obtained is largely due to the expansion of the echoes on the B scope. Since only a 30° sector is shown on this screen, while the full 360° are shown on the PPI, the line produced by the echo is longer on the B scope than the arc on the PPI. When the VF is connected to a radar having a narrow antenna beam, it may be possible to center the longer line on the B scope somewhat more accurately than to bisect the echo arc on a PPI with a cursor. Since a reference line is provided on the B scope for measuring bearing, this process is capable of greater accuracy than simple estimation on a PPI which has no cursor. However, cursors are being supplied to those equipments that do not already have them, since bisecting the echo arc is faster and perhaps more accurate than determining bearing on an A scope by maximizing the echo pip.



A. PPI screen showing targets, range marks, intensified ribbon marker with segment selected for enlargement showing brightly at 3 o'clock.

B. B scope showing enlarged presentation of targets seen within the brightened segment in A. The grid is formed by range and bearing lines.

Figure 147—Model VF PPI and B scopes.

3. Operation of Precision Repeater PPI.

It is difficult to keep the desired echo centered on the VF B scope on every revolution of the antenna. Hence, it is difficult for the operator to get accurate data on every revolution of the antenna, and considerable practice is required to enable the operator to realize the full accuracy of which the equipment is capable. Probably it will be more satisfactory to have the VF operator call his data when he obtains it accurately, rather than to attempt to have him read at fixed time intervals.

Aircraft are hard to track on the VF because they move so fast that the echo changes position radically between the successive retracings of the pattern. The fact that the maximum range on the B scope on the VF is 20 miles also makes tracking aircraft difficult. The echoes received by many air search radars may extend all the way across the VF B scope screen because of the wide antenna beam. In these circumstances it is not possible to measure bearings on the B scope, so that it is necessary for the operators to estimate bearing from the PPI but the B scope can still be used for ranging.

Since echoes from shell splashes last for only 3 to 6 seconds, it is possible that they may not show on the 30° sector displayed on the VF. However, if the antenna is rotated at high speed, the likelihood of missing the splash echo will be decreased. High receiver gain usually is required to make the splashes visible on both the PPI and B scopes. Unfortunately, when the gain is increased, echoes may be received from the antenna side lobes, resulting in confusion on the indicator. However, preliminary tests indicate that fairly reliable spotting is possible with the VF connected to an SG radar to an accuracy of ± 100 yards in range and $\pm 2°$ in deflection.

The B scope on the VF is a distorted presentation which may be misleading unless the distortion is understood. For example, any target on a collision course will travel straight down a vertical line on the indicator, but this may not be apparent without an understanding of the type B presentation. On a B-scope screen, own ship's position is represented by a horizontal line, *not* by a point as on a PPI. The B scope will be very useful in station keeping if it is desired to keep at a specified range and bearing from the guide. However, it is not possible to determine the bearing of one target from another directly from this indicator alone. As an illustration, suppose that four vessels are arranged in a square like that shown in the PPI presentation of figure 148A. It is apparent that true bearings cannot be determined without first finding the bearing of the center vertical line on the B scope. Even if this heading is known and taken into account, the bearing of targets 2, 3, and 4 from target 1 will all be incorrect on the companion B scope shown in figure 148B. Notice that the square that the targets formed on the PPI has been stretched at the bottom and compressed at the top to form a trapezoid on the B scope. The distortion introduced in this way is especially severe at the short ranges where the VF may be used for station keeping. Therefore, it is necessary that the operator realize that the B scope distorts the relative positions of targets when the VF is used for this purpose.

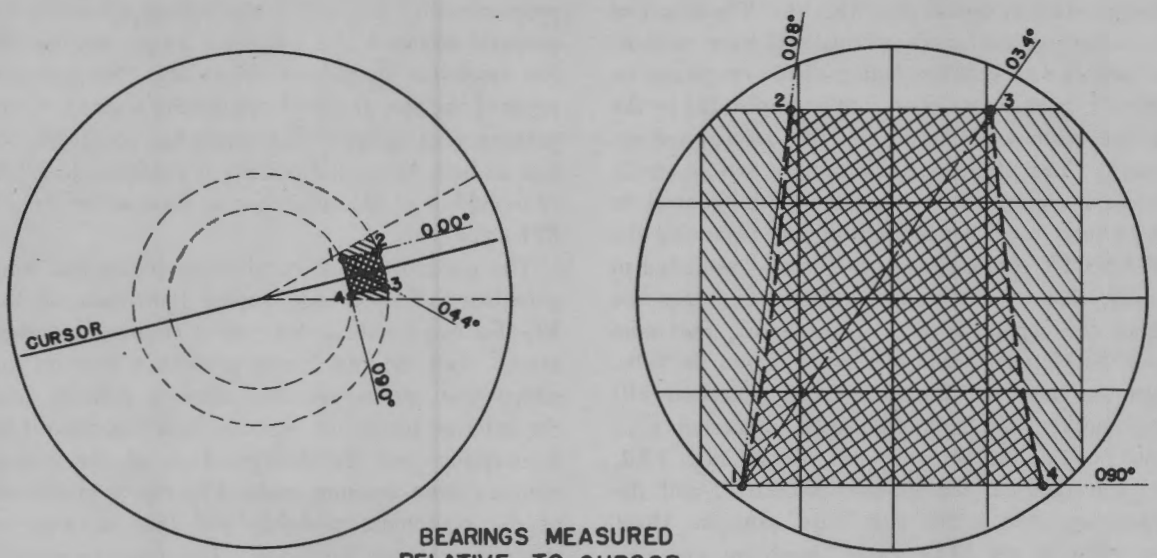


Figure 148—Distortion in B scope.

D. PROJECTION REPEATER PPI

1. Characteristics.

The projection repeater PPI is designated VG, VG-1, and VG-2. The VG and VG-1 are identical except that one is a "mirror view" of the other, so that the two equipments may be mounted end to end as a single operating unit. The electrical and optical systems of the VG-2 are identical with those of the VG, but the VG-2 has a Dead Reckoning Tracer built in. The complete unit is approximately the size of a desk, 35 inches high.

In these repeaters the scope pattern is projected on to a large horizontal surface instead of being observed directly on the face of a cathode-ray tube. The face of a 4-inch cathode-ray tube is strongly illuminated so that its image may be reflected and projected as a pattern 24 inches in diameter. The image on the screen consists of magenta-colored echoes on a white background. The image of a gyro compass repeater is projected on the same screen concentric with the radar pattern as a means of indicating the ship's course. Although the first projection PPIs produced had plain screens on which the pattern was viewed, later models will be supplied with a standard plotting surface engraved on the screen. Thus, if the equipment should fail, the surface can still be used for plotting.

The range scales provided are 4, 10, 20, 80, and 200 nautical miles. Electronically generated range markers divide the screen into four concentric rings to facilitate estimation of range.

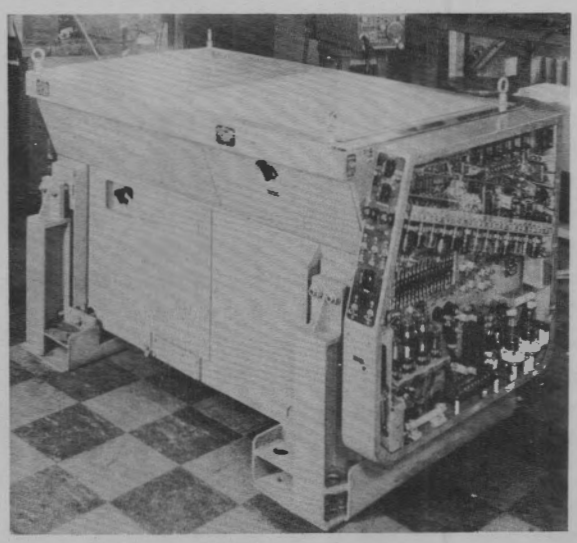


Figure 149—Type VG projection repeater PPI.

2. Operation of VG Repeater PPI.

The cathode-ray tube used in the VG is of special construction. Before the electron beam strikes the screen, it is white. The places where the electron beam strikes do not glow as in the conventional cathode-ray tube, but instead they turn a dark magenta color. The nature of the coating on the screen is such that the dark spots will stay dark almost indefinitely if neither heat nor light is directed at the screen from outside. Thus, the VG pattern is of very long persistence. To prevent the pattern from lingering too long, the VG should be operated in the "Fast Erase" position, in which hot air is blown across the cathode-ray tube screen in addition to the strong light that is normally shone on it. Such operation will not seriously shorten the life of the tube, as was originally feared, and it will result in

more satisfactory operation of the VG. The nature of the coating on the screen of this dark-trace cathode-ray tube is such that the fading of the image can be hastened if the screen is uniformly bombarded by the electron beam while heat and light are applied externally. The electron bombardment can be made reasonably uniform by turning the GAIN control on the repeater to its lowest setting and advancing the INTENSITY control, while the unit is connected to a radar that uses a high repetition rate, since the higher the repetition rate of the radar, the more often the electron beam will sweep across the tube. Thus, to erase the pattern on the projection PPI most quickly, the unit should be connected to a radar, such as the SG, that uses a fairly high PRR, the gain reduced, the intensity increased, and the repeater operated in the "Fast Erase" position. However, even in the "Fast Erase" condition, the persistence of the screen is longer than that of a conventional PPI tube, so that range scales cannot be changed without confusing the presentation for at least a few seconds.

The transmitted pulse and sea return may cause the center of the VG scope to become permanently darkened. If the burning of the screen takes place on a short range scale, detection of targets within the first few miles will be impossible on the long range scales. Burning of the screen can be prevented by the installation of a very simple modification which prevents any targets from appearing for approximately the first 500 yards of any sweep.

When the pulse repetition rate of the radar is low, relatively few echoes are returned from a given target as the antenna beam sweeps across it. Therefore, the echo on the VG cathode-ray tube screen is paler at low repetition rates than at high rates because the spot on the screen is excited less often. It is for this reason that the echoes from an SK are less intense on a VG than those from radars that operate at higher repetition rates. Consequently, the VG is not able to show the weak echoes that are returned from targets at the maximum range of the radar, which causes the maximum range of detecting targets to be somewhat less on the VG than on the more conventional PPI.

The resolution possible on long range scales with a four-inch cathode-ray tube is relatively poor because of the limitation on the minimum size of the spot. The minimum spot size on the dark trace tube is somewhat larger than on the conventional cathode-ray tube because of the nature of the coating on the screen. Enlargement of the image of the face of the four-inch tube by projecting it as a 24-inch circle on the plotting surface provides no increase in resolution because all parts of the picture are enlarged proportionally. In fact, if the optical system is not properly adjusted, the projected image may exhibit less resolution because of defocusing. No loss will result if the optical system is carefully aligned. Comparative tests indicate that somewhat poorer resolution in both range and bearing is obtained on a VG connected to an SG radar than is obtained on the SG PPI scope.

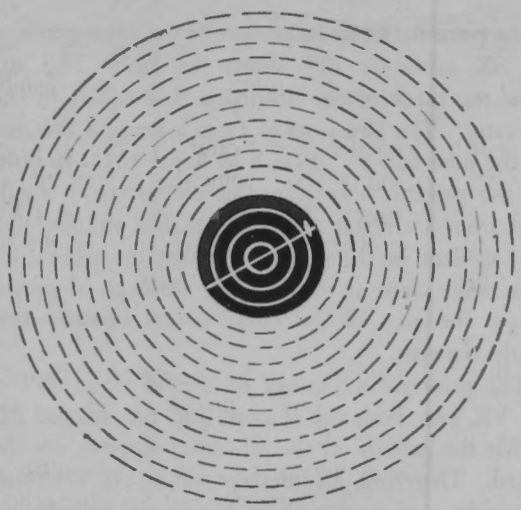
The combination of reduced resolution and long persistence of the image impose limitations on the VG that may handicap the control of aircraft to some extent. Fast moving targets produce a blur on the screen that makes accurate plotting difficult, and the inferior resolution impedes both the control of interception and the interpretation of the echoes returned from crossing raids. Experience in the use of the equipment probably will lead to ways of minimizing these handicaps. The long persistence of the image is very detrimental when the range scales are changed, and even more troublesome if any kind of jamming is encountered. Both electronic and mechanical jamming will produce large darkened areas that will remain on the screen for a long time. It will be very difficult to see targets through even a small amount of jamming because of the reduced contrast on the screen.

The procedure for adjusting the optical system of the VG must be thoroughly learned by the maintenance personnel because the whole system must be disturbed whenever the cathode-ray tube is replaced. If the adjustment procedure is not well known, the equipment may not be kept in good working order, and considerable time may be lost in changing the tube.

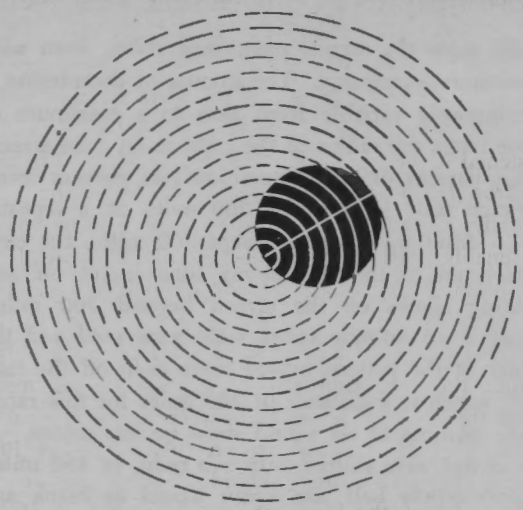
E. OFF-CENTER PPI

Recently it has been found possible to expand a section of a PPI screen without introducing appreciable distortion. The indicator which produces this expansion presents a virtual pattern on a large area of which only the small circular area of the cathode-ray tube screen is actually visible. The expansion is accomplished by moving the center of the virtual pattern off the screen to allow the outer, expanded part of the virtual presentation to fill the scope. The decentering can be accomplished in several different ways, but all result in a pattern called an off-center PPI. The method used in the SX radar produces some distortion, but an improved circuit which is to be incorporated in the VK repeater PPI presents a pattern that is as true as the one shown in a normal PPI.

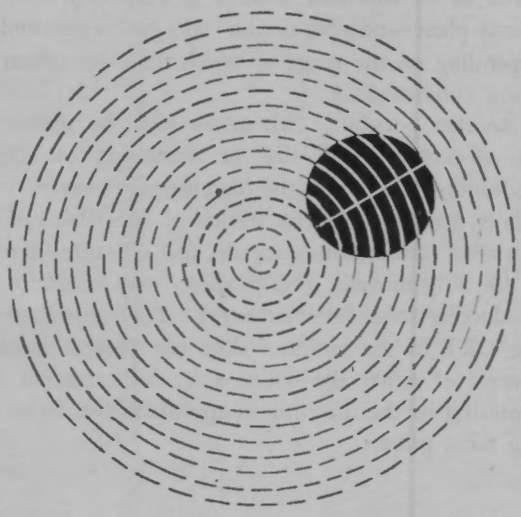
The relationship of the off-center pattern to a normal PPI pattern can be clarified by reference to figure 150. The normal PPI pattern is shown as the dark circle in A. If the cathode-ray tube screen is



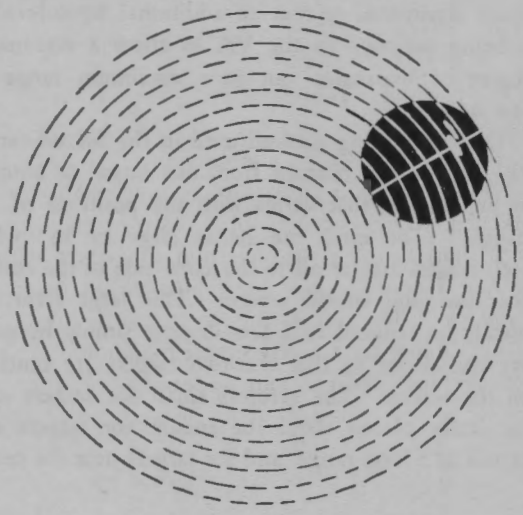
A. NORMAL – 80 MILE SCALE



B. ONE RADIUS OFF CENTER – 20 MILE RANGE SCALE



C. TWO RADII OFF CENTER – 20 MILE RANGE SCALE



D. THREE RADII OFF CENTER – 20 MILE RANGE SCALE

Figure 150—Relationship between off-center and normal PPI patterns.

12 inches in diameter, the sweep applied to the tube must be sufficient to deflect the spot to any point within a 48-inch circle. Since fluorescent material is available in this area only on the 12-inch cathode-ray tube screen, the only area that can show a trace is the 12-inch circle of the tube face. This arrangement is much like the effect of shining a spotlight on a large darkened screen. All that can be seen by the audience is the area within the brightened circle, but other parts of the screen can be brought into view by moving the spot. In figure 150, parts other than the center of the virtual 48-inch PPI can be made visible on the cathode-ray tube screen by moving the center of the pattern relative to the screen, as in B, C, and D.

If the range scale in use on the normal PPI is 10 miles long, it is possible to show targets out to 40 miles on the off-center scope by decentering the pattern. This arrangement makes it possible then to display distant targets undistorted on a sweep that permits maximum use of the resolution inherent in the radar. For example, if the normal PPI in figure 150*A* is set to the 80-mile range scale, targets at 70 miles are difficult to resolve. A great improvement can be made in the resolution if the 20-mile range scale is put in use, and the center of the PPI moved off to bring the targets onto the screen as in D. The direction in which the pattern is decentered is controlled by the cursor over the PPI. It would be possible to improve the resolution further if the 10-mile or 4-mile range scales could be used. However, since technical limitations prevent decentering the pattern by a distance greater than three times the range scale in use, neither of these range scales

could show the targets mentioned above, even with maximum decentering. The amount of decentering is continuously variable from zero to a maximum of three times the radius of the cathode-ray tube screen.

Limitations of pulse repetition rate prevent using a range scale longer than 200 miles on a repeater PPI. After the spot has swept 200 miles, the election beam in the cathode-ray tube is cut off and nothing shows on the screen beyond 200 miles. Thus, if an 80-mile range scale were used and the center of the pattern moved three radii off the tube face, which is a distance of 240 miles for this range scale, nothing at all would show on the screen. If the center were shifted only two radii, or 160 miles, approximately half the screen would be blank and the remainder would show the area between 160 and 200 miles, centered about the bearing of the cursor. The 80-mile range scale does not provide much expansion, so that an additional 40-mile scale is being supplied in the VK to allow a reasonable degree of expansion out to a maximum range of 160 miles.

The decentering method used in the SX off-center PPI distorts the bearing from one target to another by an amount that varies with the positions of the targets. The error can be as large as 36° when both targets are far off to the same side of the cursor, near the edge of the screen. This large error can readily be reduced to a few degrees simply by moving the cursor so that the two targets are centered on the screen. The error is small for targets symmetrically placed about the cursor, for targets separated by a long range, and for targets near the center of the pattern. Close inspection of the photograph of the SX off-center PPI shown in figure 151 will show the cause of the distortion that occurs in this indicator. The sweep starts from a straight line just off the tube face at 7 o'clock in figure 151. In order for the pattern to be true, the several traces should start from a circular arc rather than a straight line. It is evident in the photograph that the nearest arc of a range circle is too straight, although at greater ranges the arcs of the range circles become more nearly circular.

The principal advantage of the off-center PPI of the VK over both the B-scope and the delayed PPI is that the pattern on the off-center scope is not distorted. Therefore, an intercept officer can determine vectors to give aircraft under his control by reference to the indicator alone. The high degree of resolution provided in the off-center PPI allows the friendly plane to be followed until it is very close to the enemy plane—possibly until a "tally-ho" is reported—depending on the range at which the interception is being conducted.

Another possibility that arises with the advent of the off-center PPI is that of connecting the Dead Reckoning Tracer to the decentering circuits. If this is done, a particular section of shoreline can be made to remain stationary on the off-center screen as the ship moves. This property may be useful in conducting shore bombardments. The connection of the DRT to the indicator does not prevent manual control of either the selection of the extent of decentering or the direction along which the decentering takes place.

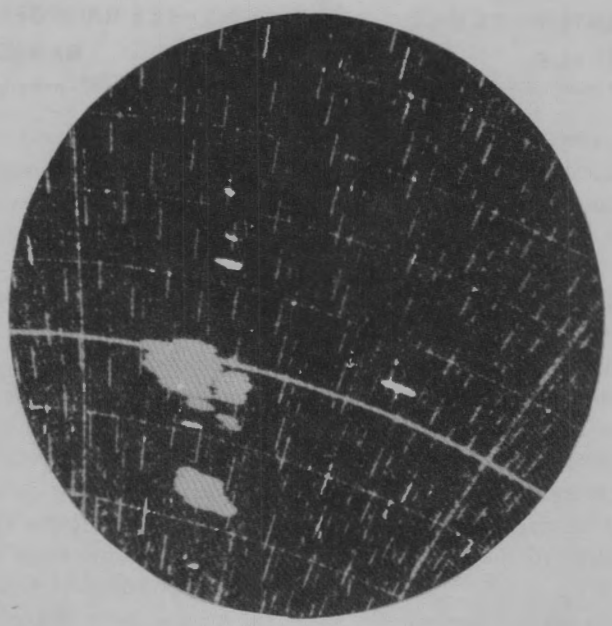


Figure 151—SX off-center PPI.

CHAPTER IX

RADAR RECOGNITION SYSTEMS — IFF

A. Introduction:

Definitions; recognition methods; development of IFF.

B. Operation of an IFF system:

Definitions; principles of an IFF system; transpondor; interrogator-responsor; G-band operation; destructors; Mark IV IFF system; Mark V IFF system.

C. Limitations of the IFF system:

Operational; propagation; resolution; materiel.

A. INTRODUCTION

1. General.

The friendly or enemy character of a radar contact cannot be determined from the appearance of the echo alone; some auxiliary means for recognition or identification must be provided. That this problem is most urgent is brought out by the following quotation from the War Instructions, United States Navy (FTP. 143):

> "516. A most important factor in war is positive recognition and identification of friend or enemy. Through lack of thorough training, absence of coordination, and due to misunderstanding, friends lose their lives or the enemy is permitted to escape. It is essential that personnel receive proper indoctrination on this subject."

The terms "Recognition" and "Identification" are defined by the War Instructions as follows:

> *Recognition:* The process of determining the friendly or enemy character of others.
>
> *Identification:* The process of indicating your own friendly character.

Several methods of determining the identity of contacts are in common use. The basic means of recognizing ships and aircraft is by familiarity with silhouettes and markings. Recognition of radar contacts sometimes can be effected by coordination of radar data with reports received from observers at a distance who can see the target. A contributory aid to recognition is the maintenance of a continuous plot of both the ships in company and own planes, utilizing both radar and visual observations. Recognition is possible by means of a process of elimination if definite knowledge is available on the location and expected course of action of all friendly units, including aircraft, in the area of operations. But, to quote the War Instructions again, "When a friend approaches whose movements are unknown to the personnel charged with recognition and identification, command has failed in an important function. Therefore, it is requisite that responsible commanders disseminate within and without their commands adequate information of expected movements and the locations of friendly units who may possibly contact each other. However, meeting a friendly ship at an expected time and place is no assurance that an enemy ship is not also in the vicinity. This is particularly true of submarines. Relying too implicitly on advance information is unsound and not an acceptable substitute for effective recognition." In some cases, a vessel identifies itself by a simple, coded radiotelegraphic transmission to a direction finder system. A submarine frequently identifies itself by keying its radar transmitter to produce coded interference on the radar indicator of another submarine.

All of these methods involve considerable coordination, and consequent time delay. Hence, it has been found essential to provide means of direct recognition at the point where the target is detected by radar. Various systems have been developed whereby aircraft and surface vessels are provided with equipment which allows them to establish their friendly character, either directly to the primary radar equipment or to additional apparatus associated with the radar. Such systems are known as IFF (Identification, Friend or Foe), although the definitions stated in the War Instructions indicate that IFF should be called a *recognition* system.

2. Development of IFF.

The development of IFF began almost as soon as the first radar set was built. In one of the earliest experimental forms a simple dipole antenna was installed in an aircraft or surface vessel. The dipole was resonant to the radar frequency, and was switched so as to produce regular fluctuations in the size of the echo received at the radar. So simple a system was soon found to be inadequate due to such factors as its uncertainty, the introduction of new radar equipment using different frequencies, and the persistent demands for recognition at greater range.

These difficulties were in part overcome by the successive introduction of IFF Mark I and Mark II. Both of these systems employed a combined receiver-

transmitter by means of which airplanes could identify themselves to radars. The set normally was in the receiving condition but when energized by the receipt of a radar signal, it broke into oscillation and became a transmitter. The signal emitted from the identification equipment was radiated to the radar station together with the normal echo from the target, and the echo was thereby distorted in such a manner as to make recognition possible. The tuning of the set was mechanically swept through the bands of radar frequencies then in use, so that the recognition of targets on any radar was aided by the reception of periodic identification signals as the receiver-transmitter set tuned through the radar frequency.

Radar equipments now operate on such a large number of widely separated frequencies that it has become impracticable to produce a single IFF set capable of tuning to all of them. To provide an adequate identification service operating in this manner it would, therefore, be necessary for aircraft and ships to carry simultaneously several different types of IFF sets. Further, it would be necessary to introduce additions and modifications to this equipment each time radar equipment on a new frequency was introduced.

Such increases in the amount of equipment carried, particularly in aircraft, could not be accepted. The difficulty has been overcome by the introduction of a universal frequency band for IFF, separate from that of the radar equipments on which the echoes must be recognized. In this manner, though the need for extra equipment still exists, it is possible to save installation of several IFF sets in each aircraft by the expedient of fitting auxiliary apparatus to the radar equipment in the ship, where considerations of weight and space are in general of less critical importance.

B. OPERATION OF AN IFF SYSTEM

1. Definitions.

The components which make up an IFF system are as follows:

1. *Interrogator:* A radio transmitter which emits signals on some frequency in the IFF band, and which is associated with the radar equipment whose echoes must be recognized.

2. *Transpondor:* A combined receiver-transmitter, fitted in all friendly aircraft and ships, which receives a challenge pulse from an Interrogator and automatically returns a signal on the same

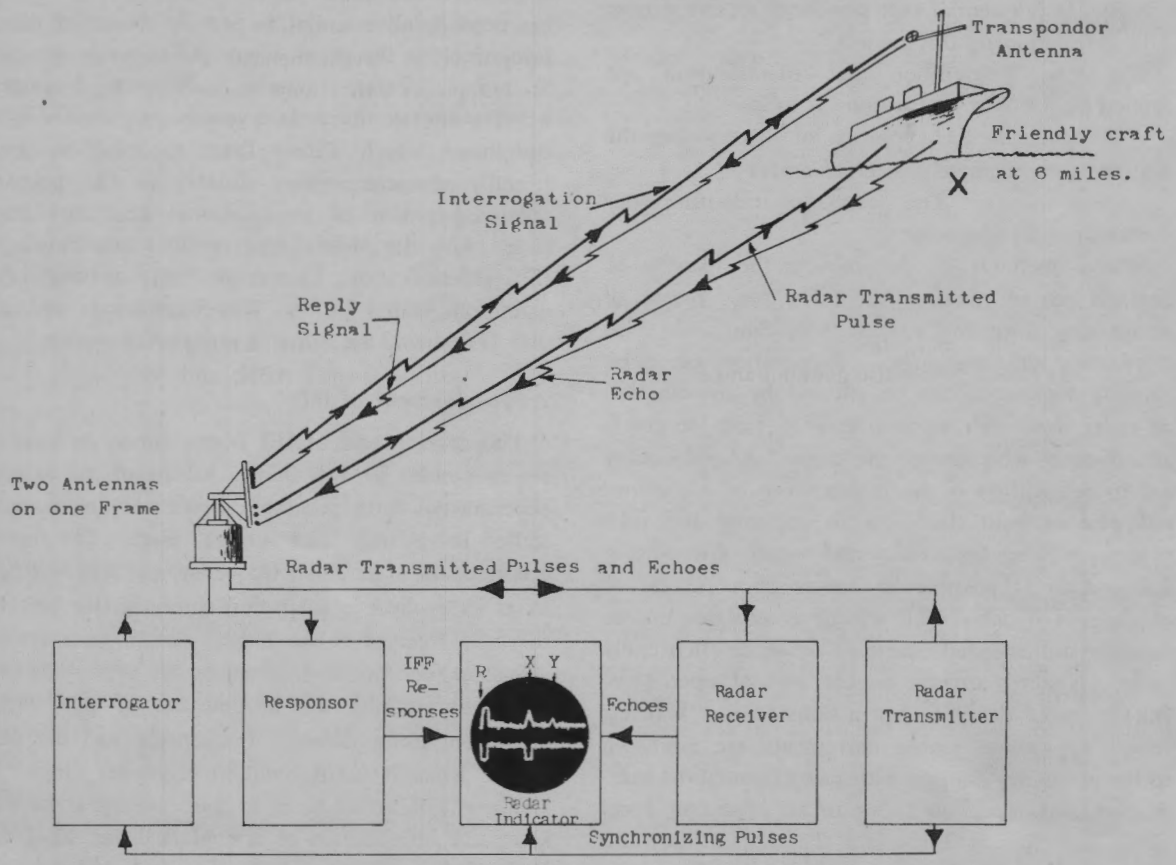


Figure 152—Block diagram of IFF systems.

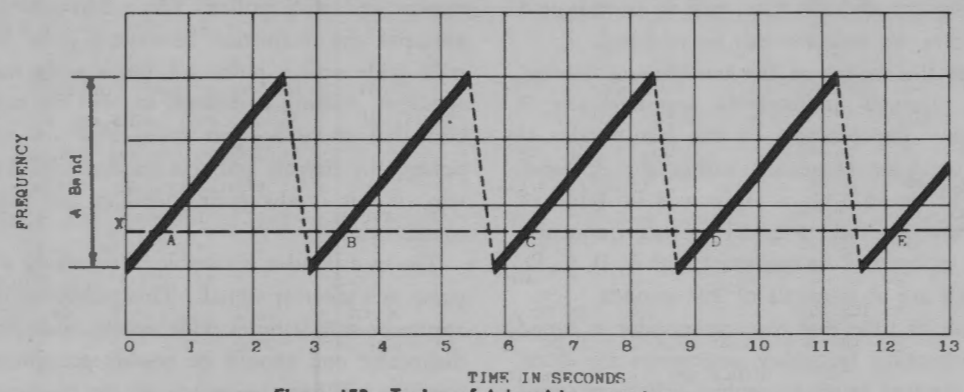


Figure 153—Tuning of A-band transpondor.

frequency (or a different frequency, depending on the IFF system in use). The form and duration of the reply signal are controlled by a coding system.

3. *Responsor:* A radio receiver, associated with the radar equipment, which receives the reply returned from the Transpondor and produces an output suitable for feeding to a display system. The Responsor is usually combined into a single unit with the Interrogator.

2. Principles of an IFF System.

A block diagram of an IFF system associated with a radar system is shown in figure 152. Both the radar indicator and the interrogator are synchronized from the radar transmitter. Thus the interrogator pulse and the radar pulse are transmitted nearly simultaneously. The IFF antenna and the radar antenna use a common reflector in the case illustrated, so that the two pulses are radiated from the same place. The radar echo from the ship is shown at *X* on the indicator and the echo from a second target, which is not illustrated, appears at *Y*. During the same time that the radar pulse is travelling out to the target, the interrogator pulse goes out and actuates the transpondor on the friendly ship. The transpondor response then returns to the antenna along with the radar echo. As a result, a negative pulse appears on the lower sweep almost directly under the echo pulse. Since the target at *Y* does not have a transpondor, it cannot identify itself as a friend. However, it must be realized that the lack of an IFF response is not a clear indication of the enemy character of a contact. The target at Y, then, is not necessarily an enemy, because the transpondor may simply not have been turned on, or the equipment may be inoperative.

3. Transpondor.

A transpondor consists of a receiver, a transmitter, and an antenna. The transmitter normally is quiescent and the receiver ready to receive. When an interrogating pulse is received, it is amplified many times. This large pulse is used to trigger the transmitter, causing it to reply to the interrogation on the frequency to which the transpondor transmitter is tuned at that instant. Circuits in the transmitter control the character of the pulse sent out, so that the interrogating pulse serves only to start the action. The action of the transpondor is entirely automatic; it needs no attention from operating personnel after it has been turned on. Whenever a pulse is received, the set automatically transmits a reply; the transpondor may be regarded as a pulse repeater or a pulse amplifier. A weak pulse is received and this device then automatically sends out a strong pulse with almost no delay. As a result, the IFF reply usually is much stronger than the radar echo, because the echo contains only a small fraction of the power of the transmitted pulse which is reflected back toward the radar.

The Mark III IFF system is in use at present throughout the world by all the United Nations. The transpondor that is used on board ship in the Navy is called the BK. An identical transpondor for use in aircraft is termed ABK, and for use by the U. S. Army, SCR 595. Other aircraft equipments that incorporate a Mark III transpondor are called ABF, SCR 695, or AN/APX-1, and AN/APX-2.

The Mark III IFF frequency band is called the A band, which is a 30-megacycle section of the P band of frequencies. Another frequency band, called the G band, is also used in the Mark III system for the recognition of fighter planes.

A Mark III transpondor is tuned mechanically over the A band in 2.5 seconds, and approximately one-third of a second is required to reset the tuning adjustment. Thus the time required for one cycle of operation of the transpondor is a little less than three seconds, but the transpondor is operative during only the 2.5-second interval of the forward sweep. This condition is indicated by the heavy lines in figure

153. During the flyback time, which is indicated by broken lines, no response can be returned.

Because of the nature of the transpondor tuning, a reply is returned at intervals approximately 3 seconds long. For example, if the transpondor is challenged on some frequency within the A band, such as X in figure 153, a reply will be returned every time that the set is tuned to this frequency. As a result, replies will be transmitted at A, B, C, D, and E, which are at intervals of 2.9 seconds.

The length of time that the transpondor is tuned to the interrogating frequency determines the duration of the interval in which replies will be returned in each cycle. However, the characteristics of the receiver in the transpondor are such that it can be actuated for a longer interval by a strong interrogating pulse than by a weak one. As a result, replies are returned for a relatively long time at short ranges, while at long range the reply is visible for only a brief time.

In the Mark III system the transpondor reply is coded by means of varying the width of the pulses transmitted on four successive frequency sweeps. A complete cycle of the code, then, is completed in a little less than 12 seconds. The elements that are used to make up the code are a narrow pulse, a wide pulse, and a blank, which is a sweep during which a response is not returned. The narrow pulse appears approximately 0.6 mile wide on the indicator, and the wide pulse approximately 1.5 miles in width. Thus, in figure 153, the responses may be:

(*a*) During the first sweep, a narrow pulse at *A*.

(*b*) During the second sweep, a narrow pulse at *B*.

(*c*) During the third sweep, a wide pulse at *C*.

(*d*) During the fourth sweep, no response at *D*, or a blank.

The fifth sweep duplicates the first, so that the code cycle is repeated.

The six codes that are available with the Mark III IFF are:

1. Narrow, narrow, narrow, narrow (NNNN)
2. Narrow, blank, narrow, blank (N–N–)
3. Narrow, narrow, narrow, blank (NNN–)
4. Narrow, narrow, wide, wide (NNWW)
5. Narrow, blank, wide, blank (N–W–)
6. Narrow, narrow, wide, blank (NNW–)

Note that the codes are so selected that each one is distinctive. No code can be mistaken for any other, no matter at what point in the cycle the response is first observed, provided the range scale is such that it is possible to distinguish between narrow and wide pulses. On a 200-mile sweep, for example, the distinction between a pulse that is 0.6 mile wide and a pulse 1.5 miles wide may not be apparent, making it difficult to read the code. Note also that there are no codes that use only wide pulses; the narrow pulse is fundamental in this system, and it is always included in the sequence for comparison.

The transpondor is capable of returning a very long pulse as a distress signal. This pulse, which appears approximately 9 miles wide on the indicator, is very distinctive and should be readily recognized by the operator. When the switch on the transpondor control box is thrown to "EMERGENCY", the coding mechanism is by-passed so that the very wide pulse is transmitted on every sweep of the transpondor, regardless of the code that has been selected previously.

4. Interrogator-Responsor.

In the Mark III IFF system the responsor is tuned to the same frequency as the interrogator. The frequency of the interrogator can be set by the technician to any point within the A band, but in general, once the frequency is set, there will be little need to change it. The interrogators of several ships operating together should be spread as wide apart over the band as possible to reduce interference and to avoid overinterrogation of the transpondors, since these sets are limited in the maximum number of responses that they can return. The responsor is a conventional radar receiver which should require little attention from operators aside from a periodic check to insure peak tuning.

The antennas in use with Mark III interrogators may be either omni-directional, and therefore fixed, or directional and mounted on the same reflector as the antenna array of the radar with which they operate. Because of the low frequency used with this IFF system, the antenna is not highly directional.

The interrogator-responsor may sometimes have its own indicator, but in almost all shipboard installations in the Navy, Mark III IFF information is displayed directly on the radar scope. In general, the responsor is so connected to a type A indicator that IFF responses produce downward pulses, while the radar echoes produce upward pulses on the screen. In older systems, both pulses were deflected from the same sweep, but in more recent designs a separate sweep is provided for the IFF display. The double-sweep type of display, which is illustrated in figure 152, retraces the echoes perhaps three times and the IFF responses once out of each four successive pulse repetition intervals. The advantage of the separate sweeps is that neither trace interferes

with the other, and the picture therefore remains more clear.

Interrogators are generally fairly small equipment. Therefore, in order to get a reasonable amount of power out, they are usually operated at a low repetition rate. This allows the transmitting tubes to be very greatly overloaded during the pulse, but it allows them a long time between pulses to cool, so that no harm is done. When the radar operates at a high repetition rate, it is necessary to divide the pulse rate by a factor of two, three, or four to operate the interrogator properly. Even though the interrogator may be pulsed only once for every four pulses sent out by the radar, the interrogator pulse must be in synchronism with the radar pulse for satisfactory operation. Most interrogators employ some sort of counting-down circuit to meet this requirement.

In most existing radar equipment the counting-down function is performed in the interrogator itself, but in new radars an auxiliary device called an IFF Coordination Unit is provided for this purpose. The IFF Coordination Unit also makes possible the adjustment of the inherent delays in the system so that IFF responses will appear at the same range as the echo from the target carrying the transpondor, and it supplies the means for producing the second sweep on which IFF responses are displayed.

The shipboard interrogators for use on the A band

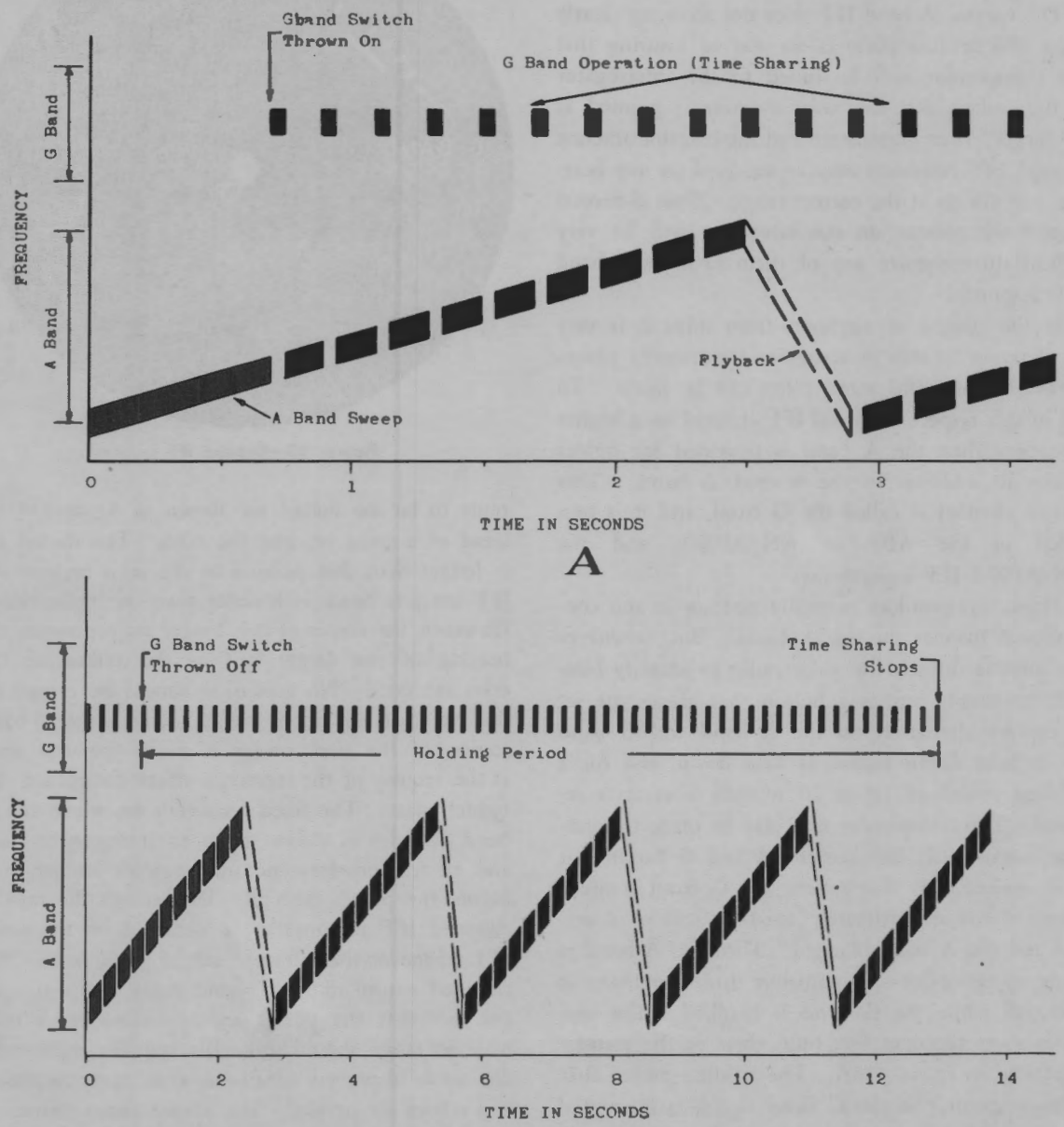


Figure 154—Time-sharing between A and G bands.

of the Mark III IFF system are designated BL, BM, and BN. The BL is for use on large ships, and the BM is an improved version incorporating higher power and other advancements for the same purpose. The BN is a small, medium power equipment designed primarily for use in small vessels, and as an auxiliary interrogator in large vessels. A fourth type of shipboard interrogator is the BO, which is designed to be used in conjunction with a radar used in fighter direction to interrogate on the G band only. Airborne interrogators are the Army SCR 729, which formerly was called ABL by the Navy, and the AN/APX-2.

5. G Band Operation.

The normal A-band IFF does not show up clearly on a PPI because there is no way of insuring that the transpondor will be tuned to the interrogator at the instant that the radar antenna is pointed at the target. If an omnidirectional interrogator antenna is used, IFF responses may be received on any bearing, but always at the correct range. Thus if several targets are present on the screen, it will be very difficult to recognize any of them by their A-band IFF responses.

In the control of airplanes from ships it is very necessary to be able to recognize the friendly planes so that a successful interception can be made. To aid in this respect, a special IFF channel on a higher frequency than the A band is provided for fighter planes in addition to the normal A band. This special channel is called the G band, and it is provided in the ABF or AN/APX-1, and the AN/APX-2 IFF equipments.

These transpondors normally operate in the conventional manner on the A band. But, whenever the pilot is directed by voice radio to identify himself, he simply pushes a button that causes the set to operate alternately on the A band and G band for as long as the button is held down, and for a holding period of 10 to 20 seconds after it is released. The transpondor may also be made to alternate continuously between the A and G bands if it is so desired. By this system, the G band is made operative for approximately one-twentieth of a second and the A band blanked. Then the A band is made operative for approximately three-twentieths of a second while the G band is blanked. The two bands share the operating time, then, in the manner illustrated in figure 154A. The holding period that follows opening of the G band switch is illustrated in figure 154B. At time 1 second the switch is thrown off but the mechanism is such that time-sharing continues for several seconds afterward—in this case 12 seconds.

Because of the time-sharing operation, the G-band response is not absolutely continuous in spite of the fact that the tuning does not sweep. Instead, the reply is chopped, or broken, at the time-sharing rate. Thus if G-band responses can be obtained over a 30° arc and the antenna is rotating at 5 revolutions per minute, the responses will be visible for one second. In this time the G-band transpondor will be turned on and off five times, causing the IFF

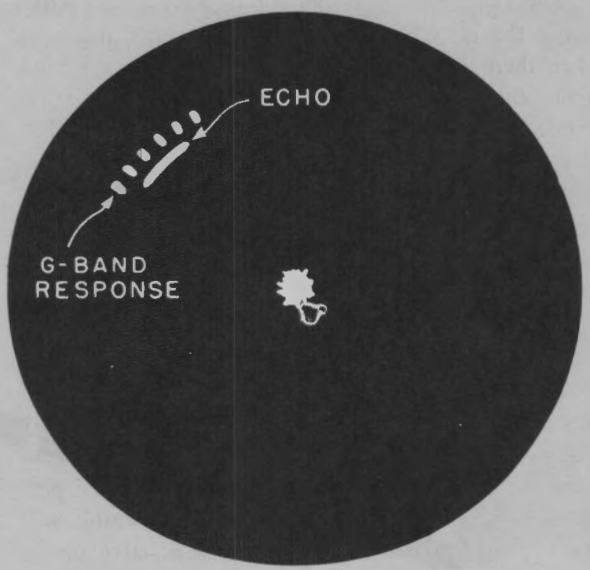


Figure 155—G-band IFF response.

reply to be the dotted arc shown in figure 155 instead of a solid arc like the echo. The dotted arc is longer than that painted by the echo because the IFF antenna beam is broader than the radar beam. However, the center of this longer arc represents the bearing of the target just as the center of the echo arc does. No confusion should be caused by the fact that the arc is broad, because the G-band section of the transpondor is made operative only at the request of the intercept officer controlling the fighter plane. The fixed frequency on which the G band operates is chosen from an 8-megacycle band and all transpondors and interrogators are set to it before the planes take off. This allows the rapidly chopped IFF response to be obtained on the radar PPI whenever the intercept officer requires it. The chopped nature of the G-band reply, coupled with the fact that the pulses are approximately a mile wide in range should make the response sufficiently distinctive to prevent confusion when many responses and echoes are present. The instantaneous characteristic of this response is especially valuable in that the IFF shows up well on a PPI scope.

6. Destructors.

The IFF system does not provide an absolute means of recognizing radar contacts. Therefore, to help insure that the responses are authentic, it is important to deny the enemy use of any transpondors that he may capture. As a means to this end, all transpondors are provided with small explosive charges which may be detonated either by an impact switch operated by the deceleration of a crash landing, or by a switch to be operated manually by the pilot whenever there is a possibility of the plane's falling in enemy territory.

The case of the transpondor is designed to withstand the force of the explosion without rupture, so that there is little danger to operating personnel from the explosion. The small charge used is intended primarily to make the set entirely useless, but not to conceal all details of the operation. Damage done by a destructor should be supplemented by any means available to insure complete destruction of the equipment when circumstances indicate such a course is warranted.

7. Mark IV IFF System.

A different system of IFF has been developed for use if the Mark III system becomes extensively compromised. Components of the Mark IV system have already been produced, but an extensive program of operational and maintenance training will be required to put this system into effective operation. The greater complexity of the Mark IV will probably cause more maintenance difficulty than is being encountered with the Mark III equipment.

The same general types of equipment are required with the Mark IV as with the Mark III. That is, challenges are sent out by *interrogators*, identifying responses returned by *transpondors*, and these responses received by *responsors*. The transpondor used with the Mark IV IFF system is called the ABA-1 or the BA-1 by the Navy and the SCR-515 by the Army. The AN/APX-1 and AN/APX-2 can be converted to Mark IV operation by the installation of a modification kit designated TN-35/-APX. A kit called the BP has been developed to convert the BN to Mark IV band operation, and the interrogator-responsor designed as part of the Mark IV system is called the BG.

The frequency of operation is higher, being in the L band, and the type of coding different than in the Mark III system. In the Mark IV system a fixed frequency is used for the challenge and a slightly different fixed frequency is used for the reply. The use of fixed frequencies eliminates the wait for a response that is necessary in the Mark III system because the transpondor sweeps over a band of frequencies. As a result of the continuous response that is received in the Mark IV system, this type of IFF is much more satisfactory for use with radars that use a PPI. In fact, the Mark IV IFF response is very similar to the G-band response in the Mark III system, except that it is not chopped.

The response pulses returned by a Mark IV transpondor are all of the same duration. Coding is accomplished by turning the transpondor off and on, so that the IFF response flashes on the screen very much like a coded blinker light. The coding cycle is of approximately twelve seconds duration. Therefore, the antenna must be stopped for this length of time to allow the code to be read; the code will not show on a PPI.

An antenna array for the Mark IV system is already built on the reflector of the antenna of search radars such as the SA-2, SC-2, and the SK. Because of the frequency used, the beam width of the Mark IV array is of the order of 7°-10°, which should provide reasonable bearing resolution for this IFF system.

8. Mark V IFF System.

Development is nearly complete on still another IFF system which has been designed in an effort to overcome many of the objections to the present system. This new system also operates in the L band, and its design takes full advantage of all the advances in ultra-high-frequency techniques made during the war. The Mark V system provides much greater flexibility of operation and much better security (in the form of an improved coding method) than is available in either the Mark III or Mark IV systems. However, this new system is complex and an extensive training program will be required to put it in service. The enormous number of ships and aircraft that the United Nations now have requires that thousands upon thousands of Mark V units be produced before the system can be put in service, since whole combat areas must convert simultaneously. Because of the enormity of the production problem, it will be a relatively long time before Mark V is put to use.

C. LIMITATIONS OF THE IFF SYSTEM

1. Operational.

The recognition of a radar contact that results from the use of IFF is in a sense a negative process. Barring compromise of the system, a properly coded response from the target enables the radar operator to recognize it as friendly, but the lack of the proper IFF response is not a clear indication of the hostile nature of a target. However, any contact which does

not respond correctly to an IFF challenge must be treated as enemy until some other means of recognition establishes its true character.

An IFF system is the only means so far developed whose capabilities of recognition match the radar's capabilities of detection. To be sure, there are several limitations inherent in the Mark III IFF system that prevent recognition of radar contacts under all conditions. Although a few of these limitations may be eliminated in future systems, it is most improbable that any practical system will be developed during this war that will be able to overcome all of the objections to the present IFF system.

In the early part of 1944, a commission was sent to the Southwest Pacific to determine the reason for the repeated reports of failure of the Mark III IFF system. Their findings may be summarized as follows:

(*a*) IFF is ineffective in nearly all theaters because the operation is poor.

(*b*) The equipment is reliable in a material sense, and it can be maintained so by relatively simple measures.

(*c*) The primary obstacle to improved effectiveness is lack of interest on the part of many responsible officers.

Operational surveys of IFF performance indicate that the percentage of ground station radar plots which are identified by IFF in the various theaters of operation are:

	Percent
Southwest Pacific	50
South Pacific	80
Mediterranean	70
Central Pacific	85
U. S. A.	75
Alaska	80

Although no such quantitative data are available on IFF performance on board Naval vessels, the fact that only a few references are made to IFF in action reports leads to the conclusion that average performance is perhaps somewhat better in the Navy than that indicated in the table above. In any case, the existing IFF system is capable of determining the identity of well over 90% of the contacts made by radar, if the system is properly employed.

Aside from the obvious danger that may result from unsuccessful operation of the IFF system, other undesirable effects may appear. When 20 or 30 unidentified flights approach daily there is no choice but to alert the ship and send fighters to intercept the contacts. If bogey afer bogey turns out to be friendly, the pilots making the interceptions begin to feel disgusted and suffer a loss in morale; the AA batteries may well become a bit slack after a series of such anticlimaxes; and all such personnel who were needlessly alerted become disgruntled. The worst feature of such failure is that the effect is cumulative. Because the gunners may have some hesitance to fire on what might be one of their own planes, the pilot whose IFF transpondor is not functioning may not be fired on. The gunners' inaction therefore tends to make the pilot even less likely to use his IFF the next time, and this failure leaves the gunners' quandary still unresolved. Such a progressive breakdown of the system can result only in mistrust of IFF as a means of recognition, with ineffective air warning and fighter direction systems as a consequence.

The recent survey of the operation of the Mark III IFF system showed that of 100 unidentified friendly radar contacts, 66 were caused by errors on the part of air personnel, 30 by obvious faults in the airborne equipment, and 4 by defects in the ground equipment or errors on the part of ground personnel. The kinds of personnel error that occur in aircraft may be given as follows:

(*a*) IFF transpondor not turned on.

(*b*) IFF turned on at wrong time (contrary to doctrine).

(*c*) IFF not in use at proper distances from own forces or territory.

(*d*) Use of improper code.

That the first of these is the most important is clearly demonstrated by the survey. Simply briefing the pilots and stationing a man at the end of the runway with a large sign bearing the legend "IFF ON?" reduced the bogey contacts from 25 to 10 per cent. Simple maintenance procedures were then instituted, and the inoperative IFF dropped to 3 per cent.

Errors in the use of IFF may arise from lack of knowledge concerning IFF, lack of indoctrination as to the use of IFF, carelessness, confusion as to the doctrine in different areas, or confusion due to different doctrine prescribed by the different branches of the services in the same area. It is apparent that these factors, which cause the largest part of the failure of the IFF system, are in no way connected with the materiel aspect of IFF. Therefore, if the Mark III system is replaced by the Mark IV or Mark V, the same problem of making the system operate effectively will be present. However, it has been demonstrated that interest and positive action by commanding officers can make the Mark III system work. Therefore, the Mark IV and any succeeding system also can be operated effectively if the officers in command maintain an interest in its operation.

Aside from the operational difficulties that may arise in the functioning of IFF as a system, certain features of Mark III IFF may hinder recognition to some extent. The responses are coded by the use of combinations of wide and narrow pulses and blanks. When a slow sweep speed is used, as in long range searching, the distinction between the wide and narrow pulses may not be sufficiently apparent to allow rapid recognition of the code. An expanded A-scope sweep, called an R scope, will be very useful in reducing this difficulty.

Since the tuning cycle of the transpondor takes nearly three seconds, the probability is small that during several successive tuning cycles a constantly-rotating antenna will point at the target at the instant when the transpondor can reply. Therefore, it is not possible to read the code from a PPI, so that the antenna must be stopped on the target for at least 12 seconds to insure recognition of friendly contacts.

Although the Mark IV system replies immediately to every interrogating pulse that strikes it, it will still be necessary to stop the antenna to read the code, since the coding cycle in this equipment also takes 12 seconds. The only type of IFF response which leads to definite recognition without stopping the antenna is that returned on the G band. This type of reply is instantaneous, but it shows only when called for from the ship, and it is "coded" by selecting the frequency on which the G band operates.

If several planes in a group all have their transpondors turned on, the many responses received will make it impossible to read the code. The operator may be able to tell if any wide pulses are being returned, but the blanks and the order in which the narrow and wide pulses occur will be obscured. The many responses returned under this condition need not confuse the echo presentation on the screen, since the responses show only when the operator throws the IFF switch on the radar operating console to the "ON" position. Similar interference is often produced by the many responses returned from a few transpondors when they are triggered by a large number of interrogators in a task group. The responses triggered by other interrogators will show as pulses that move back and forth across the trace, producing considerable confusion on the indicator. The EMERGENCY pulse is sufficiently wide that it can be recognized through considerable interference or on a slow sweep, such as the 375-mile range scale on the SK radar. Little confusion should be caused by the reception of a large number of Emergency pulses since this signal is to be used only when in distress or when standing by a friendly craft in distress.

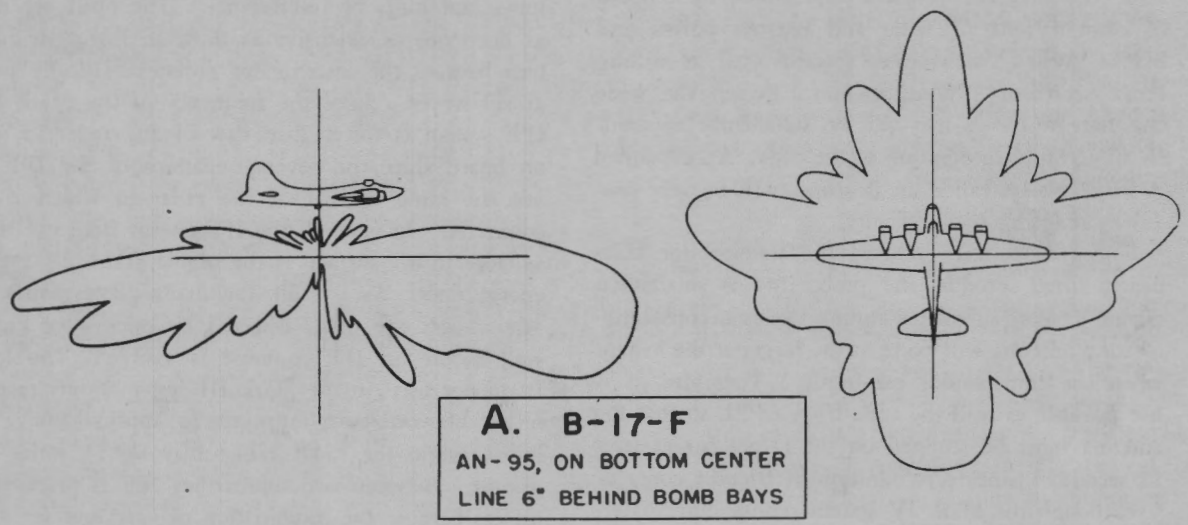
2. Propagation.

The energy radiated from the interrogator antenna strikes the water, and is therefore formed into lobes and nulls by interference. The nulls are not as deep nor as extensive as those in the radar pattern because the interrogator radiates vertically polarized waves. Since the frequency of the Mark III IFF system is lower than that of any radar in use on board ship, the coverage pattern of the IFF is not the same as that of the radar to which it is connected. In general, the IFF energy does not stay as close to the surface as the higher frequency radar energy does. As a result, low-flying planes and surface vessels are often detected by microwave radar well before an IFF response is visible. The low frequency used in the Mark III system limits recognition between two destroyers to approximately 10 miles, while the radar range may be 15 miles or greater. Between two submarines IFF is practically useless because the combination of very low antenna heights with the low frequency requires the subs to approach to a dangerously short range to obtain a response.

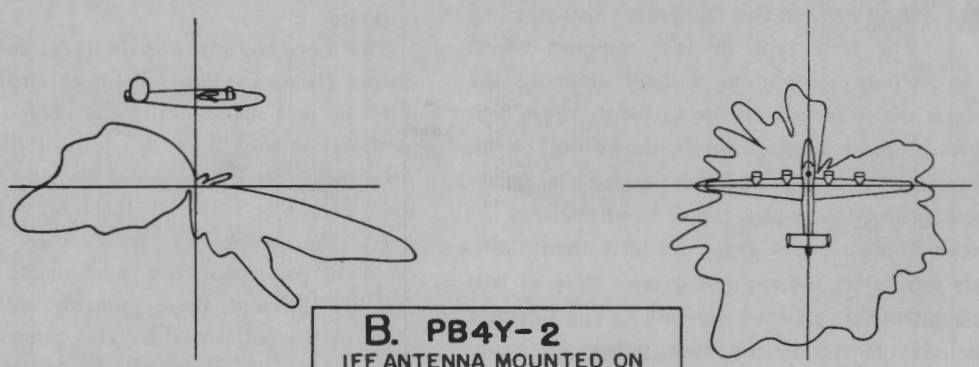
The lobes and nulls of the radar and IFF patterns do not always overlap. Thus, an airplane can sometimes be in a maximum of the radar radiation while at the same time it is in a null of the IFF pattern. As a result, an IFF response may not be returned at some ranges even though the echo is visible, and of course the reverse can also be true. However, because the patterns of the two antenna arrays in general are different, there probably will not be many areas in the pattern where this phenomenon occurs. In any case, the plane will fly out of the null in a minute or two, so that if the radar operator is familiar with the fade pattern of the radar, there should be little confusion caused.

When the fade charts of the radar are calibrated by flight tests, an IFF fade chart can be derived by keeping the transpondor in the plane energized, and observing both the radar echo and the IFF responses during the test. Such a pattern for IFF would serve not only to indicate the areas in which IFF and radar nulls overlap, but also to provide additional data for estimating the height of friendly planes. The IFF pattern will be more reliable if the transpondor tuning is fixed at the interrogator frequency during the test run, since the continuous reply thus produced will make it easier to determine null areas.

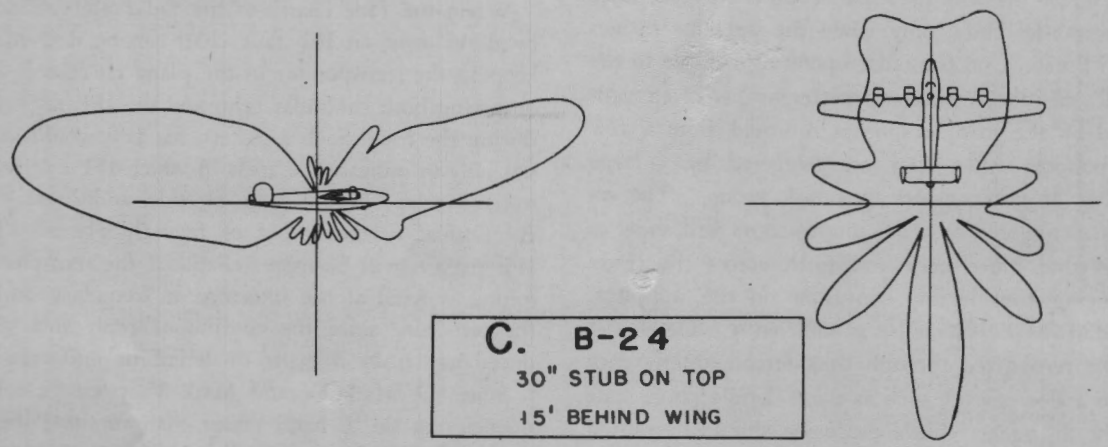
Since the Mark IV and Mark V systems use frequencies in the L band rather than in the P band, they should be capable of greater range on low-flying aircraft and between surface vessels than the Mark III system. The greater range is possible because the high-frequency energy stays closer to the water than



A. B-17-F
AN-95, ON BOTTOM CENTER
LINE 6" BEHIND BOMB BAYS



B. PB4Y-2
IFF ANTENNA MOUNTED ON
THE BOTTOM 9.30' FROM
TAIL, 0.25' TO STBD.



C. B-24
30" STUB ON TOP
15' BEHIND WING

Figure 156—Transpondor coverage patterns of airplanes.

the lower-frequency radiation of the current system.

Japanese radar pulses can trigger both the A and G bands of the Mark III IFF transpondors. The responses show up on the Japanese indicators more or less like normal echoes that vary with the code set on the transpondor. The range from which the responses are received is always greater than that from which the radar echo is returned, because the transpondor serves as an amplifier for the Japanese radar pulse. For example, if the maximum range at which a plane can be detected is 70 miles, the transpondor conceivably could be triggered by the enemy radar at a range of 100 miles. Since the IFF response will in general be much stronger than the radar echo, the IFF response will show even though the echo is not visible. This is a very great advantage to the enemy since it extends the range of his radar for detecting our planes. Therefore, IFF transpondors should be turned off as airplanes approach enemy territory.

In areas covered by both enemy and friendly radars it is necessary to strike a balance between the advantage of keeping the transpondor energized to assist in recognition of radar contacts and the danger of aiding the enemy by extending the effective range of some of his radars. It is important to realize that the Mark III IFF can serve as a recognition system for the Japanese as well as for us, without their having to capture a single transpondor. From the Japanese point of view, targets that return an IFF response are enemy.

In general, it is more important for returning planes to have their transpondors energized than for planes that are flying away from their base. However, on long strikes the pilots must be briefed on the approximate positions of any friendly forces along their route, so that IFF can be on when the planes approach such forces. Unfortunately, several planes have neglected this simple precaution and have been shot down by friends.

The range at which an IFF response can be obtained from a target is dependent on the height of the interrogator antenna and the height of the transpondor antenna. The range is not related to the size of the target in any way except that antennas probably can be mounted higher on large craft than on small. Thus, the IFF range on a single fighter plane is just as great as that on a flight of large bombers. Of course, the maximum range at which an IFF response can be returned is dependent also on the power radiated by the interrogator and the transpondor, the sensitivity of the receivers in each of these pieces of equipment, and on the existing propagation conditions. If the radar itself were capable of triggering the transpondor, IFF would always show at ranges greater than those from which echoes can be obtained because the transpondor would serve as a pulse amplifier. However, the gain introduced by the transpondor is offset almost completely by the relatively low power radiated by the interrogator in the Mark III system. As a result, the range at which a challenge can just trigger the ABK transpondor is very nearly the same as the range at which an echo is just visible.

At very short ranges the interrogator-responsor can act as a radar. Since relatively low power is radiated by the interrogator, echoes from nearby large targets may clutter the first mile or two of the sweep. This clutter may limit the minimum range at which IFF responses can be read, and it may confuse the operator by the constant downward deflection of the trace on the indicator screen. The Mark IV IFF system will not be affected by echoes from nearby targets because the responsor receives on a different frequency than that on which the interrogator transmits.

Omnidirectional antennas are always used with transpondors in order that the ship or aircraft can be challenged and reply in any direction. However, these antennas rarely have perfectly uniform coverage because they cannot be mounted in a position free of obstruction on all bearings. Representative coverage patterns for large airplanes are shown in figure 156. Note particularly the poor forward coverage of the antenna mounted below and toward the rear in the case of the PB4Y-2 in *B*, and the sharp null to the starboard side forward caused by the off-center installation. Notice the generally good coverage of the B-17 installation in *A*. In *C*, the transpondor antenna is mounted on the top of the B-24 so that the coverage underneath is poor.

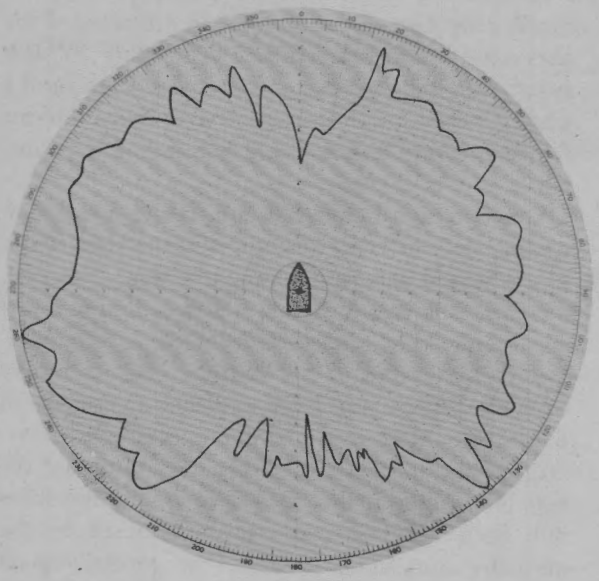
Since there are more obstructions on ships than on planes, it is reasonable to expect that the coverage patterns of shipboard omnidirectional antennas will be less uniform than those on planes. In figure 157*B* is shown the pattern of a BN antenna which is mounted on the port side, amidships. The pattern is far from uniform, having very poor coverage on relative bearings of 015° and 100°, with deep nulls at other angles. With a pattern such as this it would be very difficult to get a response from a target bearing 100° relative, for example. Figures 157 *C* and *D* show the coverage patterns for two BK's on the same ship. Where possible two transpondors are supplied so that the antenna of one may fill the gaps in the pattern of the other. However, note here that both patterns are weak on the port beam, although the coverage to starboard is excellent. One of the antennas should be moved to a point that would produce more uniform coverage. In *A* is

shown the pattern of a BM, which uses a directional antenna mounted on the air search antenna reflector. Because the array is on top of a stub mast amidships and has negligible obstruction in its field of view, the coverage is good at all bearings.

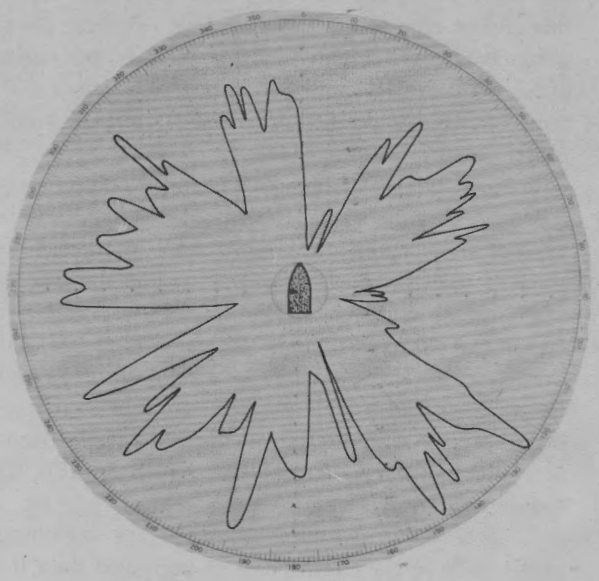
3. Resolution.

Since an omnidirectional antenna sends out energy in all directions, no resolution in bearing is possible. Thus, if several targets are at nearly the same range, but at widely different bearings, a single friendly contact may identify all the targets as friendly. An omnidirectional antenna on an interrogator, then, is useful only when all targets are separated by a distance great enough to permit range resolution.

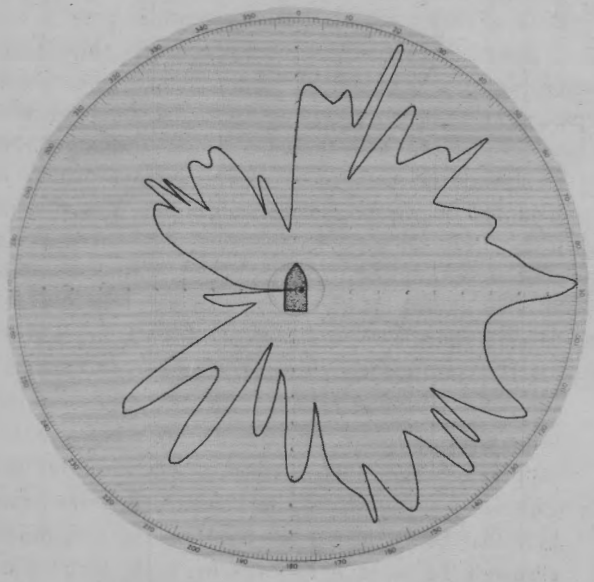
The directional antenna provided with some Mark III interrogators has a very broad pattern because space limitations will not permit a highly directional array to be built for the low frequency at which the IFF system operates. In general, these antennas have bad side lobes in addition to rather broad main lobes, but the side lobes in figure 158B are accentuated by reflections from obstructions in the antenna field. The pattern in A is more nearly like the free-space pattern because very little of the ship's structure interferes with the radiation. Note that the main lobes in both cases are asymmetrical. The asymmetry and the many side lobes are indicative of reflections from the ship's structure. Since the amount of in-



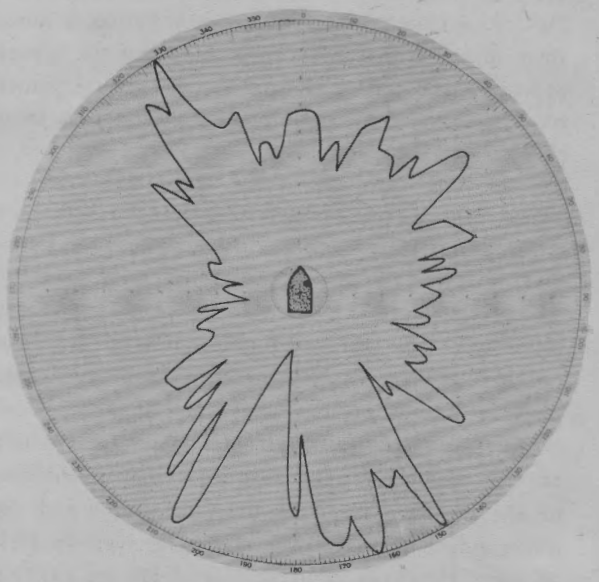
A. BM antenna on foremast.



B. BN antenna on port yardarm.



C. BK antenna on starboard yardarm.

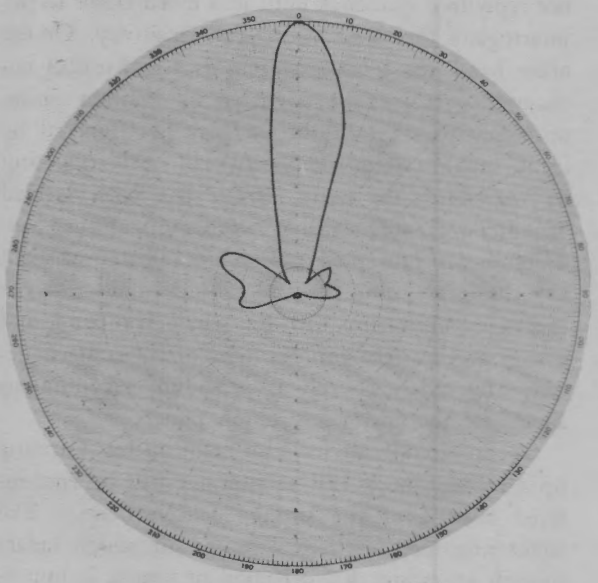


D. BK antenna on starboard side forward.

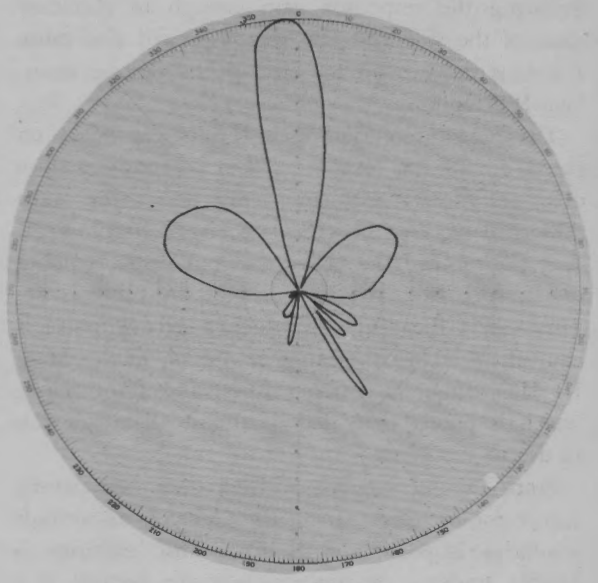
Figure 157—Coverage diagrams for shipborne IFF equipment.

terference caused by reflection varies as the antenna is rotated, the shape of the antenna pattern is dependent to some extent on the relative bearing to which it is trained. The beam widths shown in figure 158 are approximately 20°, but in some cases the beams may be considerably wider. Consequently, the bearing resolution of a Mark III IFF interrogator is worse than that of any of the radars with which it may be associated. The bad side lobes that appear on some relative bearings, as in figure 158*B* for example, distort the antenna pattern so badly that IFF responses may be returned from a nearby friendly target over nearly the full 360°, from enemy targets are friendly because part of the IFF response appears near the echo. Maintenance of an accurate surface plot is probably the only reliable means of insuring that all radar contacts can be recognized during a melee.

Because the Mark IV IFF system uses higher frequency than the Mark III, the interrogator beam width can be made narrow enough to provide reasonable bearing resolution. The Mark IV antennas which are built on the reflecting screens of current air search radars provide beam widths on the order of 7° to 10°, so that bearing resolution with this system should be better than 5°.



A. Beam width .....20°
Maximum side lobe.....31%
Back lobe 22%



B. Beam width .....18°
Maximum side lobe.....53%
Back lobe 41%

Figure 158—Patterns of directional Mark III interrogator antennas.

irrespective of antenna bearing. In order to permit the operator to observe IFF responses from either of two targets at the same range without confusion from the other, the angular separation between the targets must be 10° to 20°.

The side lobes of the interrogator antenna may often result in IFF responses being returned from bearings at which no radar echo appears. Recognition of friendly ships in a melee is almost impossible because of the confusion produced by the poor bearing resolution of the interrogators, the false responses triggered by side and back lobes, the multiplicity of responses that make it impossible to read the code, and the short IFF range possible between surface vessels. The IFF responses from a single friendly target show over a wide arc on the indicator because of the wide antenna beam and the many side lobes. This may lead the operator to believe that echoes

The nature of the IFF system is such that reducing responsor gain has less effect on side lobe IFF responses than reducing receiver gain has on radar echoes produced by side lobes. The power radiated in the side lobe is very much less than that in the main lobe. The signal developed at the radar receiver terminals as the result of a given echo power entering a side lobe is much less than if the same power entered the main lobe. These two factors act together to keep side-lobe echoes smaller than the desired echoes produced by the main lobe. Reducing receiver gain causes a greater decrease in the size of the side-lobe echoes than in the desired echoes, and in many cases, the side-lobe radar echoes can be entirely eliminated from the screen without serious loss of the desired signals. In the IFF system, however, if the interrogating power is sufficient to trigger the transpondor, a full-power response is

returned, and the strength of the response is not increased if the interrogating signal is made stronger. For example, in figure 158B, the minor lobe at 235° Relative is only 5% of the major lobe. If a target is close enough that its transpondor will be triggered by this minor lobe, full-power responses will be returned in every lobe of the antenna. The strength of the signal at the responsor terminals produced by the side-lobe response is less than that produced by the main lobe response, but not nearly as much so as in the case of a radar echo. Consequently, the responsor is not as able as a radar receiver to discriminate between main-lobe and side-lobe signals. Reducing the responsor gain enough to eliminate most of the side-lobe IFF responses will also cause a serious decrease in the size of the desired main-lobe IFF replies.

The range resolution with IFF is dependent on the width of the response pulses. However, since every code in use includes narrow pulses, the range difference required between two targets to allow the operator to read the code from one target without interference from the responses of the other is approximately the range to which a narrow pulse is equivalent. Thus the range resolution in the Mark III IFF system is between 1,000 and 1,500 yards, which is poorer than that of almost all radars now in use in the Navy.

Since the interrogator antenna does not elevate, except for interrogators on the G band, no altitude resolution is possible with IFF. This limitation is largely academic in practice, however, because it is not likely that two airborne targets, or an airplane and a ship, will remain for long within the distance required for range resolution. The limited physical size of the G-band IFF antenna necessitates a broad antenna beam in both horizontal and vertical directions. As a result, the position angle resolution for G-band interrogators is poor.

4. Materiel.

There is inherent in the IFF system a small amount of delay that prevents the IFF response from coinciding exactly with the radar echo on the indicator screen. In some cases, as when the counting-down circuit of the interrogator is improperly adjusted, the delay may be as much as a mile. In general, however, the delay will be between 400 and 1,000 yards. In some cases it may be desirable to leave a small delay in the system to facilitate viewing the IFF responses. This delay causes the response and the echo with which it is associated to be slightly separated on the indicator. Radars of recent design incorporate an IFF coordinator which provides for a double trace on the A scope, and permits adjustment of the delays in the system so that the IFF response will appear directly under the proper echo.

Vibration that is encountered in normal use may cause the tuning range of a transpondor to change. If this change tunes the set out of the high end of the band, it may be triggered directly by some of the lower frequency P-band air search radars. Such responses would appear as upward deflections, rather than downward in the manner of normal IFF signals received by the responsor. An adequate program of inspection and testing should prevent such trouble.

The sensitivity of a transpondor decreases as the vacuum tubes age. An insensitive transpondor will not reply to a challenge until it is much closer to the interrogator than a set having full sensitivity. On the other hand, too great sensitivity is also harmful because the set may be triggered by ignition noises or other sparking, or the set may be triggered by itself, should certain components fail. Self-triggering or responding to noise, which has been termed "squitter", is objectionable because under this condition many unwanted pulses are radiated without any challenge being received. Thus, squitter causes excessive interference with the whole IFF band, and it may prevent recognition of any of the contacts detected by radar, as well as providing a continuous signal for the enemy's direction finders.

On an aircraft carrier with many planes warming up on deck, much IFF squittering may be encountered because of the strong ignition noise. The squittering may interfere with the air search radars to such an extent that detection of targets is impossible during the warm-up interval. In most cases this sort of interference should not appear on the indicator because the responsor output shows only when the IFF switch is thrown on. However, in aircraft carriers where the radar frequency is not far from the IFF frequency band, the transpondor pulses will cause interference because they are strong enough to go through the radar receiver in spite of the frequency difference.

When the Mark III IFF was first installed there were some air search radars that operated at frequencies within the Mark III band. This overlap caused confusion since it was impossible to refrain from interrogating every friendly target detected, and the responses caused upward deflection rather than downward. To avoid this difficulty all "red" SC's were set to another frequency band, and the "green" equipments were tuned to the high end of the band.

The Mark III transpondor transmits very low power pulses continuously at a 300 kilocycle rate, even though no interrogating pulses are received. These small pulses may cause considerable interference that has the appearance of strong grass each

time the transpondor sweeps through the radar frequency. As a means of reducing this interference from a BK to a radar on the same ship, the transpondor is made inoperative, or suppressed, for a time equivalent to 100 miles range every time the radar pulses. The suppression is synchronized to the pulse repetition rate of the SA, SC, or SK radar. In some cases this same sort of interference is produced through the responsor, even though the radar receiver is tuned to a frequency considerably different from the IFF band. Thus, the BK usually will need suppression from the air search radars, irrespective of the frequency to which the radar is tuned. The policy of the Bureau of Ships relative to suppression of Mark III IFF transpondors is published in section 5 of the Radar Maintenance Bulletin.

In some cases the TBS and other VHF equipment causes interference with the IFF system. When the communication signals are picked up by the responsor, the whole trace on the radar indicator is deflected in accordance with the radio signal.

On the other hand, the transpondor may interfere with communications. The transpondor puts out noise signals at frequencies up to approximately 20 megacycles, but most of these frequencies are detectable over a very short range only. The principal interfering signals produced by the transpondor are on 300 kilocycles and 600 kilocycles, so that communications on these frequencies may be somewhat impeded. If serious interference is encountered on 300 kc or 600 kc, the frequency of the oscillator that generates this signal in the transpondor may be shifted without affecting the operation of the set, provided the AGS circuit is also retuned.

Interference with the IFF system and that produced in other equipment by IFF can be reduced by the proper selection of the operating frequency of the interrogator-responsor, by the use of filters in the equipment that suffers the interference, and by cleaning and checking insulation in the radar. Much ignition noise can be avoided on aircraft carriers by proper grounding of the cowling and magneto and by thorough checking of the spark plugs.

When a plane is in the air, the pilot has no reliable means of determining if his transpondor is operating properly. There is a jack on the control box into which he can plug his headphones and hear a tone when the set in replying to interrogation, but if he hears no tone, he has no way of knowing whether he is not being challenged or whether the transpondor is defective. An adequate maintenance program can remedy this difficulty by insuring that all installed transpondors are in excellent condition. The frequency limits and sensitivity of the transpondors should be checked at frequent regular intervals, and the whole installation given a superficial daily inspection in order to find and replace any broken parts.

The Mark IV IFF system has certain advantages over the Mark III because of the higher operating frequency. But, since all the interrogators operate on the same fixed frequency and all the transpondors on a slightly different fixed frequency, keeping all the units tuned properly will pose a considerable maintenance problem if this system is put in use. However, if adequate test equipment is made available to the Fleet, there should be little difficulty in keeping the Mark IV system operative after the operational experience gained in the use of the Mark III IFF system.

CHAPTER X

RADAR BEACONS — RACON

A. Introduction — Uses of beacons.

B. Method of operation:

Similarity to IFF; types of coding; distinction between radar and radio beacons.

C. Types of radar beacons.

D. Capabilities and limitations.

A. INTRODUCTION

Radar beacons, or Racons as they have been named, are used to return a distinctive signal to a radar in much the same way that an IFF transpondor replies to an interrogator. Their principal use is to provide a strong signal so that airplanes can home by radar on a carrier or land base from a long distance. Consequently, beacons are classified as navigational aids. Other beacons may be used to provide a strong signal on a featureless shore as a means of facilitating radar navigation of ships, or to provide a reference point for shore bombardment. Radar beacons are installed in many shore establishments, and are on the allowance list for all CV, CVB, CVL, and CVE's. The radio call letters and the codes by which each racon identifies itself are published in a series of six books entitled "Racon List" published by the Hydrographic Office, U. S. Navy, with the approval of the Combined Communications Board. The short titles of these books are CCBP 02 to CCBP 07, inclusive.

B. METHOD OF OPERATION

A radar beacon is a fixed-frequency transpondor that is interrogated by the pulses transmitted by a radar. Therefore, a separate racon transpondor must be produced for every frequency band on which beacon responses are desired. Since many radar frequency bands are in use, there are many different types of beacons in use.

The radar beacon transpondor normally is quiescent, in a receiving condition. When a pulse of the proper frequency and duration is received, the equipment automatically becomes a transmitter to return a coded response that identifies the beacon as well as indicating the range from the challenging radar.

The receiver tuning is made rather broad in order that a single racon can respond to challenges from any radar within a given band, because a beacon transpondor does not sweep in frequency as the Mark III IFF transpondor does on the A band. Since the beacon replies to each challenging pulse, the responses appear as continuous pips on the radar indicator.

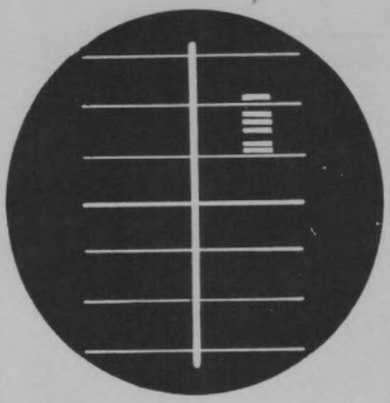
The radar beacon transmitter frequency is slightly different from the frequency to which the receiver is tuned. For example, if one type of racon is actuated by a pulse at 176 megacycles, it will respond on 177.5 megacycles. Thus, the receiver of the radar that challenges a radar beacon must be detuned from the radar frequency in order to accept the beacon response. As a result, a radar can be used either to challenge a racon or to search for targets, but never for both operations simultaneously. The reason for designing the beacons for this type of operation is to prevent interference between radar echoes and racon responses. Therefore, signals returned from racons are clearly visible on the indicator because the clutter of sea return and echoes from land is eliminated. Another beneficial feature of this type of operation is that racon responses may be viewed on a clear scope in one installation, while an adjacent radar in the same frequency band may search normally without interference from the radar beacons.

Most airborne radars have been designed for use with beacons, so that such operation is made easy and convenient. The microwave beacons that are designed to be challenged by airborne radars will not respond to the normal search pulses transmitted by the radar. Therefore, when it is desired to interrogate a radar beacon, the "Beacon" switch is thrown, causing the radar transmitted pulse duration to be increased, while at the same time the radar receiver is automatically tuned to the racon response frequency. Shipboard radars, on the other hand, have seldom been used with racons, and tuning the radar receiver to the racon response is a manual process not facilitated by any special provisions for beacon operation.

There are two different means of automatic coding of the racon responses in use at present. On the P and L band beacons the responses are coded by interrupting the responses at intervals to form the Morse code letters that identify the beacon. Normally the beacon signal appears steady on the indicator, but every 30 seconds the response pip winks off and on like a blinker light. This type of code is called "gap coding" because the identification is accom-

A. PPI INDICATOR

Range 50 miles
Bearing 335°
Code 1-2-1



B. B INDICATOR

Range 41 miles
Bearing 45° starboard
Code 2-3-1

Figure 159—Range-coded beacon response.

plished by inserting gaps in the normally continuous response.

Microwave beacons, however, use range coding as a means of identification. In this system several pulses separated by spaces of variable width are returned for each interrogating signal, causing the response to extend out in range from the actual range of the racon. The number of pulses and the relative spacing between each pulse form the code. Between two and six pulses and either narrow or wide spacing are used. The code usually is specified by giving the number of pips in each closely-spaced group. For example, a particular beacon might transmit the following: pip-long space, pip-short space-pip, long space-pip. The code would then be specified as 1–2–1.

The range to a beacon is given by the range to the first code pip. The bearing is given by the center line of the pips. Figure 159 shows the appearance of a PPI and a B scope with a range-coded beacon response showing. This type of reply is advantageous because the beacon identifies itself on every response, which eliminates any delay in recognizing its geographic position.

Radio homing beacons, or sector-coded beacons, are designed for use on aircraft carriers or at airfields to provide an omnidirectional homing or navigational signal for the guidance of aircraft. The transmitter is keyed in twenty-four 15° sectors with 000° centered on true north. The directional antenna, rotating at a speed of two revolutions per minute, radiates a differently coded modulated CW signal in each sector for nine revolutions, and during the tenth revolution it radiates an identification signal. The homing beacons, which are designated YE and YG, are very different from radar beacons in that instead of being actuated by an interrogating signal from the plane, these beacons transmit continuously without the plane's having to do more than receive the signals sent out. Since the YE and the YG are radio beacons which operate on principles entirely different from those on which radar beacons operate, these equipments are not racons.

C. TYPES OF RADAR BEACONS

Since racon transpondors operate on fixed frequencies, there are many racons in existence. Those that are likely to be found on board ship are given in the table on opposite page.

The YJ serves two frequency bands since it can respond alternately to a frequency within the A band of the Mark III system and to the frequency on which the ASB radars operate. The YJ is widely installed, and the identifying gap-coded response from each shore station is indicated in the Racon List. The AN/CPN-3, 6, 8 and 17 will not respond to interrogation from shipboard radars because the frequencies assigned to these radars within the S and X bands are different from those assigned to the airborne radars.

The Mark 2 is simply an improvement on the Mark 1 to reduce weight and to permit response either to the Mark 3 or 4 or to the Mark 12 fire control radars. The Mark 4 beacon is to be produced in three models having different power supplies. The Mark 5 is a modification of a racon designated AN/UPN-1 or AN/UPN-2 which may be available during the first part of 1945.

Designation	*Frequency Band*	*For Use With*	*Installation*
YJ-1 YJ-2	P and L	ASE, SCR 521, SCR 729, AN/APX-2. All ASB type radar.	Ship, shore.
AN/CPN-3, AN/CPN-8	S	All S-band airborne radar.	Shore.
AN/CPN-6	X	All X-band airborne radar.	Ship, shore.
AN/CPN-17	S	All S-band airborne radar.	Ship, shore.
Mark 1, Mod 1	L	Mark 3/4 fire control radar.	Portable, 100 pounds.
Mark 2, Mod 0	L	Mark 3/4 fire control radar.	Portable, 40 pounds.
Mark 2, Mod 1	L	Mark 12 fire control radar.	Portable. 40 pounds,
Mark 4, Mods 0, 1, 2	S	Mark 8, Mark 28 fire control radar.	Shore.
Mark 5, Mods 0, 1	S	Mark 8, Mark 28 fire control radar.	Portable.

D. CAPABILITIES AND LIMITATIONS

The range at which a racon response can be received is dependent on the height of the challenging craft, the power radiated by the racon, and the height of the racon antenna. For low position angles the range is greatly affected by propagation conditions. Usually, if a plane cannot get a response from a racon it should climb to a higher altitude. However, when the weather is such as to cause excessive bending of the radiated rays, the plane may be able to get a response by flying at a low altitude. If the plane flies within the duct formed by non-standard propagation conditions, exceptionally long ranges may be observed on racon stations.

The curves shown in figure 160 are very approximate indications of the reliable ranges that can be obtained on the YJ, AN/CPN-3, and AN/CPN-6 racons under standard conditions as the height of the interrogating plane is varied. The curves show clearly that the S-band energy of the AN/CPN-3 stays much closer to the surface of the earth than does the L-band energy of the YJ.

The Mark 1 Mod 1 racon, being portable, is a low-power equipment. When it is set up on land, the racon response can be detected at a maximum range of approximately 25,000 yards. If the same set is installed in a spotting plane, the response can be detected out to approximately 50,000 yards. The ranges on the Mark 2 beacon will probably be of the same order.

In all racon transpondors there is a small constant error in the indicated range because of the delay that the signal suffers in actuating the transpondor. This delay is inherent in the set and it cannot be eliminated entirely because the response of the transpondor cannot be made absolutely instantaneous. In navigational racons this delay causes a negligible error. However, in fire control accurate data are desired, so that the error caused by the transpondor delay must be considered in beacons used for providing a reference point for shore bombardment. The delay in the Mark 1 beacon is approximately one microsecond, which causes all the indicated ranges to be approximately 150 yards longer than the true range. Therefore, in using beacons in connection with shore bombardment, the inherent error must be determined, and the error subtracted from the ranges indicated on the radar.

Since a radar that is used to challenge a beacon cannot be used simultaneously as a detection device, it is not possible to spot the fall of shot with a radar while observing beacon responses on it. The Mark 4 and Mark 12 radars have rather poor bearing resolution, which makes them of limited use in ranging on land. With either the Mark 1 or Mark 2 racons available, the utility of these radars would be considerably increased in shore bombardment actions. Any radar spotting that is to be done can be performed by some radar other than the one observing the racon responses.

After sufficient practice, it is claimed that the technician can retune a Mark 4 fire control radar for normal radar operation in about 10 seconds. Thus, using this radar for interrogating a beacon does not limit to any great extent the use of the equipment as a radar. If retuning from beacon to radar is to be accomplished within this short time, however, the receiver sensitivity for the beacon response will be far less than for a radar echo. This difference is due to the use of radio-frequency amplifiers in the Mark 4 receiver. These amplifiers are either left tuned to the radar frequency or by-passed, reducing the radar receiver sensitivity for beacon responses in either case. If it were decided not to attempt to change back to normal radar operation

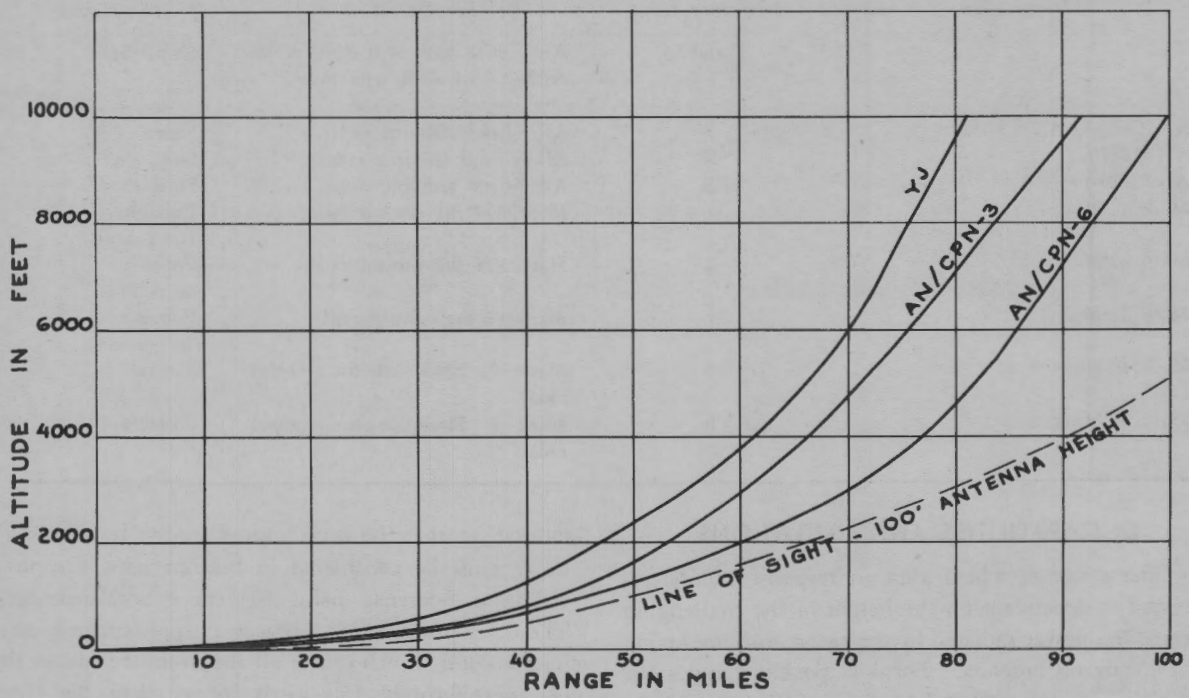


Figure 160—Approximate maximum reliable range on radar beacons.

very quickly, the beacon responses could be detected well beyond 25,000 yards. With radars that are provided with an Automatic Frequency Control Circuit (AFC) the receiver local oscillator can be manually tuned to the beacon response, and the radar retuned for normal operation almost instantly by turning on the AFC. This type of operation could be very helpful in extending the use of the radar.

Since portable beacons must be supplied power from batteries, the useful life of the racon is limited by the life of the batteries. The Mark 1 Mod 1 racon weighs 100 pounds complete, of which 60 pounds are in batteries. With these batteries the racon can operate continuously for 6 hours. If half the weight of batteries is used, the set can operate continuously for only two and a half hours.

The shore fire control party is considerably handicapped by having to carry equipment as heavy as the Mark 1 Mod 1 racon. The Mark 2 Mod 0 racon, which weighs only 40 pounds, was therefore developed to reduce the load. With the lighter equipment the shore fire control party will be enabled to get in position more quickly and to operate successfully over rougher terrain than would be possible with the heavier equipment.

APPENDIX A

GLOSSARY OF RADAR TERMS

This glossary was compiled largely by selecting terms from the following sources:

Radar Electronic Fundamentals ..... NavShips 900,016

Radar System Fundamentals ..... NavShips 900,017

Glossary of Terms used in Connection with Radiation Laboratory Radar ..... H. Shapiro, 15 November, 1943

Glossary of Radar Terms ..... AN/APQ-13 Instruction Book

Radar Technical Bulletin No. 4 ..... Eng. 129

The following additional publications give definitions also suited to radar:

Symbols and Abbreviations ..... BuShips Specification 16S12(RE)

U. S. Navy Symbols—

Report No. 58 from Ship's Statistics Report—Materiel Branch of BuShips

Glossary of Physics ..... Weld

American Standard Definitions of Electrical Terms ..... AIEE

GLOSSARY OF RADAR TERMS

A BAND—A frequency band used in Mark III IFF. Transpondors that operate in this band are continually tuned through it, causing responses to a particular interrogating frequency to be transmitted at 3-second intervals. These responses are coded in that the pulse duration is varied by the coding mechanism. See *G Band.*

"A" INDICATOR—An indicator on which a time sweep produces a horizontal range scale on which echo signals appear as vertical deflections (also called *"A" scan* and *"A" scope*).

ABSOLUTE ALTIMETER—An electronic instrument which furnishes altitude data, in feet, with respect to the surface of the earth, as distinguished from an aneroid altimeter whose readings are based on air pressure and therefore functions with respect to sea level. See *Altimeter.*

AC—Alternating current.

ACCELERATION MERIT—Ratio of acceleration (in degrees/-sec.^{2}) to angular lag (in degrees) in a servo system.

ACORN TUBES—Small receiving tubes, made in the shape of acorns, and having good high frequency characteristics.

AEW—Aircraft early warning radar. A high-power set installed in aircraft for long-range detection.

AFC—Automatic Frequency Control.

AGC—Automatic Gain Control.

AGL—Airborne gun laying; radar for plane-to-plane fire control.

AI—Aircraft interception. Radar which enables a night fighter to detect and close with an enemy aircraft.

AIDED TRACKING—A system of tracking a signal in azimuth, elevation, or range in which a constant rate of motion of the tracking mechanism is maintained by mechanical means so that an equivalent constant rate of motion of the target can be followed.

AIR GAP—An air space between two objects which are electrically or magnetically related. For example, the space between electrodes of a spark gap or the space separating sections of an iron core transformer. It is used to provide a high impedence path for electron flow and a high reluctance path for magnetic flux.

AJ—See *Anti-Jamming.*

ALIGNMENT—(1) The process of adjusting the tuned circuits of a tuned radio-frequency receiver to a predesignated natural frequency.

(2) The process of adjusting two or more components of a system so that their functions are properly synchronized; for example, antenna orientation and PPI sweep.

ALTERNATING CURRENT (AC)—Current that is continually changing in magnitude and periodically reversing in polarity.

ALTIMETER—An instrument that indicates the elevation of an aircraft above a given level. A barometric or aneroid altimeter does this by measuring the weight of air above it and thus indicates height above sea level, or some other selected reference plane. A radio altimeter, usually referred to as an absolute altimeter, utilizes the time interval between the transmission of a radio signal and the return of its echo from the ground to measure absolute altitude.

ALTITUDE—(1) Corrected altitude is the true height above sea level. (2) Absolute altitude is the true height above the ground.

AMBIENT TEMPERATURE—The temperature of the surrounding cooling medium, such as gas or liquid, which comes in contact with the heated parts of the apparatus, e. g., temperature inside airplane or in a compartment of a ship.

AMPLIDYNE GENERATOR—A special type of DC generator used as an electromechanical amplifier. A small amount of field power can control a large power output, and the response of the output voltage to changes in field excitation is very rapid. The amplidyne generator is used with radar equipment to control the speed and direction of rotation of the antenna driving motor.

AMPLIFICATION—The process of increasing the amplitude (either current or voltage or both) of an electrical signal.

AMPLIFIER—A device for increasing the power, voltage or current of a given input, in which the output of a local source of power is controlled by the input signal.

AMPLITUDE—In connection with alternating current or any other periodic phenomena, the maximum value of the displacement from the zero position.

AMPLITUDE BALANCE—A control for balancing the amplitude of signals on separate traces.

AMPLITUDE DISTORTION—A condition in which the output voltage of an amplifier is not directly proportional to the input voltage over the complete range of the input voltage.

AMPLITUDE MODULATION (AM)—An operation in which the amplitude of a radio wave is made to vary in accordance with the signal containing the intelligence to be transmitted; the frequency and phase angle of the radio wave remain constant.

ANGLE COMPONENT SOLVER—A machine which resolves an electrical vector into its components. See *Electrical Resolver* and *Resolver.*

ANGULAR RATE—Rate of change of bearing.

ANODE—Any electrode of a vacuum tube or cathode ray tube operated at higher d-c potential than the cathode (e.g., plate, screen grid, focusing anodes, accelerating anode, etc.).

ANOMALOUS PROPAGATION—See *Trapping.*

ANTENNA—A conductor or a system of conductors for radiating or receiving radio waves.

ANTENNA ASSEMBLY—The complete equipment associated with projecting radar waves into space and receiving them, consisting in general of a mounting base, gears and motors for rotating the antenna, synchros, potentiometers, the antenna proper, and the reflector, together with associated switches, such as those used in sector scanning, and the switch used to set up a ship's head marker on the PPI tube.

ANTENNA BEARING—The generated bearing of the antenna as delivered to the indicator or PPI; generally true bearing, but may be relative, depending on operating conditions. (A separate circuit is generally used to indicate the transmission of relative bearings.)

ANTENNA CONTROL—Control governing rotation of antenna —direction, speed, servo, slewing, etc.

ANTENNA DISCONNECT SWITCH—Safety switch or interlock plug to remove driving power from antenna to prevent rotation while work is being performed on it.

ANTENNA MATCHING DEVICE—A device which matches the antenna to its transmission line by introducing an impedance which together with the impedance of the antenna equals the characteristic impedance of the line.

ANTENNA PEDESTAL—Support for antenna assembly containing training motor, gears, synchros, rotating joint, etc.

ANTENNA REFLECTOR—That portion of a directional array, frequently indirectly excited, which reduces the field intensity behind the array and increases it in the forward direction.

ANTENNA SWITCHING UNIT—The TR box.

ANTI-AIRCRAFT FIRE CONTROL RADAR—Equipment for precision long-range fire control, and for defense against low-flying planes such as dive bombers and ground attack planes.

ANTI-HUNT—A feedback signal or network in a servo mechanism acting to prevent "hunting" or oscillation of the system. Special types of anti-hunt circuits are: *Anticipators, Derivitive, Velocity Feedback,* and *Dampers.*

ANTI-JAMMING (AJ)—(1) The art of minimizing the effect of enemy counter-measures in order to permit the echoes from targets detected by the radar to be visible on the indicator. (2) The controls or circuit features incorporated to minimize jamming.

ANTI-T-R BOX—A device similar to a T-R box used to tune the transmitter section of the r-f line so that returning echoes do not enter the transmitter. Also called the *R-T box* or *ATR box.*

APERTURE (OF AN ANTENNA)—Diameter of the reflector (dish). Usually measured in terms of wavelengths.

AQUADAG—A colloidal suspension of graphite deposited on the inner side walls of cathode-ray tubes to serve as an electrostatic shield or as an accelerating anode.

ARRAY—A number of antenna elements arranged so as to produce a concentration of energy in a desired direction.

ARTIFICIAL LINE—A circuit made up of lumped constants (inductors, capacitors and/or resistors) which is used to simulate the delay or pulse-forming characteristics of a long transmission line.

ASC—Automatic sensitivity control.

ASTIGMATISM—Variation of focus along trace of CRT.

ASV—Aircraft to surface vessel. Radar to detect surface vessels from patrol aircraft.

ATR BOX—See *Anti-TR Box.*

ATTENUATION—Reduction in the strength of an electrical impulse or signal.

ATTENUATOR—A device for reducing the amplitude of a signal. RF attenuators are of two general types. The first, or "cut-off type," operates on the principle of a wave guide below cut-off. The second, or "dissipative type," introduces dissipative elements to absorb energy. In coaxial-line dissipative attenuators the loss may be introduced either in the form of series resistance or shunt conductance. Examples of the former are the platinized glass rod and carbonized rod attenuators. Shunt conductance types are ordinary lossy cable and sand loads.

AUTOMATIC—Applicable to any system which carries on its function without manual control.

AUTOMATIC FREQUENCY CONTROL (AFC)—The control of the frequency of a generating system within a narrow range. Usually control of local oscillator frequency as a means of keeping the receiver accurately tuned.

AUTOMATIC GAIN CONTROL (AGC)—A type of circuit used to maintain the output of a receiver constant, regardless of variations in the signal strength applied to the receiver. In radar, the echo from any selected target, which is within the range gate, is used to control the gain of the whole receiver, so that echoes from other than the selected target appear to vary more than usual.

AUTOMATIC GAIN STABILIZATION (AGS)—A circuit used with superregenerative receivers for the purpose of maintaining optimum sensitivity by keeping the noise pulse level constant. Such a circuit is desirable because it prevents the receiver from becoming so sensitive that the noise pulses would trigger the transmitter which is usually associated with a superregenerative receiver in IFF and radar beacon equipment.

AUTOMATIC SENSITIVITY CONTROL (ASC)—A circuit used for automatically maintaining receiver sensitivity at a predetermined level. Similar to AGC, but it affects the receiver constantly rather than during the brief interval selected by the range gate.

AUTOMATIC TRACKING—Tracking in which the servo mechanism follows the signal automatically, and keeps the radar beam oriented on the target.

AUTOMATIC TRAIN—Automatic training of the antenna in azimuth by automatic following of the target.

AUTOMATIC VOLUME CONTROL (AVC)—A circuit which develops a d-c voltage proportional to the amplitude of the carrier wave for the purpose of varying the gain of the receiver so that a constant volume of sound is heard. The operation of this circuit is independent of both the carrier frequency and the modulation imposed on the radio waves. In radar, if the modulation of the received carrier wave, that is the echo pulses, is not used, then there is no signal available for use in an AVC circuit. Therefore, the term AVC has no meaning when applied to radar, and Automatic Gain Control should be used instead.

AUXILIARY CONTROL UNIT—Unit containing supplementary controls to main control and general control.

AUXILIARY-NORMAL—A control used for selecting the source of main power to system.

AZIMUTH—Angular position or bearing in a horizontal plane measured from a zero degree relative or true north to the target in a clockwise direction from 0 to 360°.

AZIMUTH RATE—Rate of change of true bearing.

AZIMUTH-STABILIZED PPI—A PPI presentation in which 12 o'clock on the tube face is made always to represent true north, irrespective of the heading of the vessel carrying the indicator. The stabilization is effected by introducing synchro voltages from the compass into the servo system that drives the PPI coils.

B INDICATOR—A type of presentation in which signals appear as bright spots on a rectangular grid. Azimuth is shown horizontally and range vertically. Also called *B scan* and *B scope.*

B+ (B PLUS)—Symbol used to designate the point in a circuit to which the positive terminal of the d-c supply is to be connected.

BABS—Beacon system for controlling the blind approach of aircraft.

BACK BIAS—An AJ circuit used to aid the receiver in discriminating against signals of duration longer than a normal echo pulse.

(1) *Unamplified back bias* is a degenerative voltage developed across a fast time constant circuit within an amplifier stage itself.

(2) *Amplified back bias* is a degenerative voltage developed across a fast time constant circuit within a stage of an amplifier and fed back into a preceding stage.

BACK SWING—That portion of a pulse which occurs near the end of the pulse, during which the voltage shifts in a direction opposite to that of the main body of the pulse.

BALANCE (BAL)—AJ control of video balance.

BAND PASS OR BAND WIDTH (Δ f or B)—The number of cycles per second expressing the difference between the limiting frequencies at which the desired fraction (usually half power) of the maximum output is obtained. Term applies to all types of amplifiers.

BASE LINE—The horizontal (or vertical) line formed by the movement of the sweep on a cathode-ray tube. *Sweep* usually used.

BATTERY—Two or more dry cells or storage cells connected together to serve as a d-c voltage source.

BATTLE SHORT—A switch for short-circuiting the safety interlocks and lighting a red warning light.

BAZOOKA—A device used to match an unbalanced high frequency transmission system into a balanced system or vice versa.

BEACON—See *Radar Beacon.*

BEADED TRANSMISSION LINE—A transmission line using beads to maintain the inner conductor coaxial with the outer.

BEAD SUPPORT—Ceramic or plastic beads used to support the inner conductor in coaxial transmission lines.

BEAM CURRENT—The electron stream flowing from cathode to the fluorescent screen and then to the second anode in a cathode-ray tube. This current is usually on the order of the 25 microamperes.

BEAM WIDTH—The angle between half-power intensities in lobe pattern. See *Lobe.*

BEARING—The direction of the line of sight from radar antenna to target. Azimuth angle of train. See *True* and *Relative.*

BEARING BUZZER—Circuit to indicate transmission of bearing to remote station.

BEARING CURSOR—Mechanical bearing line on *PPI* for reading target bearing.

BEARING MARK—Electronic bearing line on *PPI.* See *SHM.*

BEAT FREQUENCY—A frequency resulting from the combination of two different frequencies in a non-linear device, such as a vacuum tube or a crystal. It is numerically equal to the sum or difference of these two frequencies.

BEAT FREQUENCY OSCILLATOR (BFO)—See *Local Oscillator.*

BEAVER TAIL BEAM—A fan-shaped beam.

BEDSPRINGS—See *Billboard Type Antenna.*

BIAS—A d-c potential applied between control grid and cathode of a vacuum tube. It determines the zero signal level about which the grid operates.

BILLBOARD TYPE ANTENNA—A large broadside array with flat reflector.

BLANKING PULSE—A square wave (positive or negative) used to switch off a part of a radar system electronically, for a predetermined length of time. See *Unblanking Pulse.*

BLEEDER—See *Bleeder Resistor.*

BLEEDER CURRENT—A current drawn continuously from a power supply to improve its voltage regulation or to increase the value of voltage drop across a particular resistor.

BLEEDER RESISTOR—A resistive network used to draw a fixed current from a power supply, for purposes of regulation. Also used to provide a slow discharge path across high voltage capacitors.

BLIND ZONES—Areas in which echoes cannot be received.

BLIP—Echo indication on a type A scope. The indication is produced by a short, sharply-peaked pulse of voltage.

BLOCK DIAGRAM—A diagram in which the essential units of any system are drawn in the form of rectangles usually, and their relation to each other indicated by appropriate connecting lines.

BLOCKING CAPACITOR—A capacitor used in some branch of a circuit for the purpose of preventing the flow of direct current, or limiting the flow of low-frequency alternating current, without materially affecting the flow of high-frequency alternating current.

BLOCKING OSCILLATOR—A circuit containing a vacuum tube and a transformer which produces pulses at a predetermined repetition rate. May be free running or under control of a synchronizing voltage.

BLOCKING OSCILLATOR DRIVER—A circuit which develops a square pulse used to drive the modulator tubes, and usually contains a line-controlled blocking oscillator that shapes the pulse into the square wave.

BLOOMING—The expansion of the spot on a cathode-ray tube due to maladjustment of bias, focus and intensity.

BLOWER—A motor-driven fan used to supply air for cooling purposes.

BLOWER ALARM—Indicator light which lights if unit overheats due to blower failure.

BLOWN FUSE INDICATOR—Neon warning light, across fuse, which lights when fuse is blown.

BOLOMETER—A piece of test equipment used to measure high-frequency current or power. The sensitive element absorbs r-f power, its temperature changes, and consequently its resistance is altered.

BOND—Electrical interconnection made with a low-resistance material between chassis, metal shield cans, cable shielding braid, and other supposedly equipotential points, in order to eliminate undesirable interaction resulting from high impedance paths between them.

BOOTSTRAP DRIVER—A special type of vacuum tube circuit used to produce a square pulse to drive the modulator tube. The duration of the square pulse is determined by a pulse-forming line. The circuit is called a bootstrap driver because voltages on both sides of the pulse-forming line are raised simultaneously with voltages in the output pulse, but their relative difference (on both sides of the pulse-forming line) is not affected by the considerable voltage rise in the output pulse.

BREAKDOWN VOLTAGE—The voltage at which the electric field produced becomes strong enough to break down or ionize the insulation, gas, or air separating two conductors, thereby causing current to flow between them.

BRIDGE—An electrical network consisting usually of four branches, often represented in the form of a diamond-shaped figure. One pair of diagonally opposite corners is connected to the input and the other pair to the output circuit. Used in many types of measurements, in rectifiers, and in some oscillators. See *Wein Bridge Oscillator.*

BRIGHTNESS CONTROL—See *Intensity Control.*

BRILLIANCE CONTROL—See *Intensity Control.*

BROADSIDE ARRAY—A directional antenna system designed to give the maximum radiation in a direction perpendicular to the plane of the array, as in the SC and SK antennas.

BTO—Radar equipment designed to allow bombing through overcast.

BUG—(1) The moving element of a *DRT* (Dead Reckoning Tracer). (2) A diamond-shaped marker for reading bearings against graduated scale of fixed or moving bearing dials.

BUNCHER—The element in a velocity-modulated tube which alternately slows down and speeds up the electrons so that they are formed into groups or bunches at some point along the path of the electron beam.

BUPS—Ultraportable S-band beacon for Army plane and ground cooperation.

BURN-OUT—Loss of crystal sensitivity when excessive power is applied to it.

BUZZER—Warning device to indicate bearing or range transmission, overheating, etc.

BY-PASS CAPACITOR—A capacitor which provides an alternating-current path of comparatively low impedence around some circuit element.

C INDICATOR—A type of radar indicator in which the signal appears as a bright spot with azimuth angle as the horizontal coordinate and elevation angle as the vertical coordinate. Also called *C scan* and *C scope.*

C & I—Control and Indicator. Range operator's position in Mark 4 radar.

CALIBRATE—Position to which a control may be set to check frequency, range marks, or other functions against a standard.

CALIBRATION MARKERS—Indications on the screen of a radar indicator which divide the range scale into accurately known intervals for range determination, or checking against mechanical indicating dials, scales, or counters.

CAPACITANCE—The property of two or more bodies which enables them to store electrical energy in an electrostatic field between the bodies.

CAPACITANCE COUPLING—A method of coupling between two electrical circuits in which a capacitor's property of passing an alternating current or voltage and blocking direct current or voltage is utilized. See *RC coupling.*

CAPACITANCE DIVIDER—A circuit made up of capacitors for measuring accurately the value of a high-voltage pulse by making available only a conveniently small fraction of the total pulse voltage for the measurement.

CAPACITOR—An electrical circuit element which consists of two electrodes or sets of electrodes in the form of metal sheets or plates separated from each other by an insulating material called a dielectric.

CAPACITOR-START MOTOR—An a-c split-phase induction motor in which a capacitor is connected in series with an auxiliary winding to provide a means of starting. When the motor gets up to speed, the capacitor is disconnected by a centrifugally operated switch, and the motor runs as an ordinary single-phase induction motor. Such motors are used for rotating heavy spinners and for operating the lobe switching mechanisms in radar antennas.

CARBON PILE REGULATOR—A device whose resistance decreases in accordance with the pressure or compression applied. It is used to regulate the output of small generators.

CARRIER—A pure radio-frequency wave which is used as the vehicle for conveying intelligence by radio.

CASCADE AMPLIFIER—An amplifier of several stages, the output of one being the input of the next.

CAT WHISKER—A wire which touches the crystal in a crystal detector.

CATCHER—That electrode in a velocity modulated vacuum tube on which the spaced electron groups induce a signal. The output of the tube is taken from this element.

CATHODE—That electrode in a vacuum tube which, when heated, provides the primary source of electrons in the tube.

CATHODE FOLLOWER—A vacuum tube and its associated circuit in which the output signal is taken from the cathode circuit rather than the plate circuit. This provides a low impedance voltage source. There is no polarity reversal in this type of operation and the voltage gain of the stage is never greater than one.

CATHODE RAY—The electron stream that flows in a cathode ray tube and which after acceleration may be focused and deflected. See *Beam Current* and *Cathode-Ray Tube.*

CATHODE-RAY OSCILLOSCOPE—A test instrument which, when properly adjusted, makes possible the visual inspection of a-c signals. It consists usually of three major parts—an amplifier, time base generating circuits, and cathode-ray tube (CRT) for translation of electrical energy into light energy.

CATHODE-RAY TUBE—A vacuum tube in which an electron beam is accelerated and focused in an electron gun. This electron beam is then made to strike a layer of fluorescent material which converts the electron energy into light energy. By inserting a changing field, either electric or magnetic, between the electron gun and the fluorescent screen, this spot of light may be deflected or moved in accordance with the field variations.

CAVITY RESONATOR—A hollow metallic cavity in which electromagnetic oscillations can exist when properly excited. These determine the oscillating frequencies of klystrons, McNally tubes, and Sheppard tubes. Frequency is determined by the physical dimensions of the resonator.

CENTER EXPAND—Movement of start of PPI sweep from center of CRT so as to give a hole in center of the pattern.

CENTERING CONTROL—A control used for positioning the image on the screen of a CRT, by either changing the d-c potential on the deflection plates in the electrostatic system or changing the direct current flowing through the deflection coils in the magnetic system.

CERAMIC BEAD—A wafer type insulator used to support and insulate the center conductor of a coaxial line.

CHALLENGE—To cause an interrogator to send out pulses, putting the IFF system in operation.

CHANNEL—A group of circuits through which a signal passes. Each circuit may, in some fashion, alter the appearance of this signal.

CHARACTERISTIC IMPEDANCE—The ratio of the potential difference applied to a transmission line to the resultant current at the point where the potential difference is applied when the line is of infinite length.

CHARGING CURRENT—(1) Current that flows to charge a pulser capacitor. (2) Current that flows to restore energy to a storage battery.

CHEESE ANTENNA—Truncated parabolic reflector with horizontal enclosures at top and bottom giving rectangular opening for radiation.

CHOKE—An inductance normally used to impede alternating or transient currents without affecting appreciably the direct current.

CHOKE FLANGE—A flange put around a transmission line to prevent energy from feeding back along the outside of the line.

CHOKE JOINT—A type of joint for connecting two sections of waveguide together. It permits efficient energy transfer without the necessity of an electrical contact at the inside surfaces of the guide.

CIC—Combat Information Center. See *RadSix.*

CIRCUIT—One or more electrical parts (vacuum tubes, resistors, coils, capacitors) so interconnected as to permit current to flow when a voltage is applied.

CIRCULAR SCAN—Method of scanning of lobe of antenna radiation through 360° in a single plane.

CIRCULARITY—Control on a PPI to give equal radial deflection on all bearings.

CLAMPING CIRCUIT—A circuit which maintains either amplitude extremity of a waveform at a certain level of potential.

CLIPPER—A vacuum tube and its associated circuits which does not pass certain unwanted portions of a signal. A clipper is usually thought of as passing only the peak (positive or negative) of the signal. It can be arranged to clip any amount of the positive or negative half cycle by proper biasing.

CLUTTER—The obliteration of targets on the screen of a radar indicator due to atmospheric conditions or other targets. Ground, cloud, or sea clutter.

COARSE—Control for making rough adjustment of intensity, gain, tuning, etc.

COAXIAL CABLE—A two-conductor cable in which one conductor is a shield or tube and the other is centrally located within it. Its major feature is low loss at high frequencies. It is available in both flexible and rigid types.

COAXIALLY FED LINEAR ARRAY—A beacon antenna having a uniform azimuth pattern. Each element consists of three dipoles of the slotted type, with $\lambda g/2$ spacing between the elements.

CODER—A beacon circuit which takes the trigger pulse output of the discriminator, forms it into a series of pulses, and then feeds these pulses to the modulator circuit.

CODING DISC—Disc with small projections for operating contacts to give a certain predetermined code to the transmission.

COHO—A type of local oscillator which is used to provide a reference phase in a coherent pulse doppler system. It is locked in phase to the transmitter pulse every time a pulse is sent out. See *Stalo.*

COIL—An electrical circuit element consisting of a number of turns of wire so arranged physically as to offer impedance to the flow of alternating current through them. The impedance is a function of the frequency and the inductance, which in turn depends on the number of turns and method of winding.

COINCIDENCE AMPLIFIER—An amplifier which has an output only when two pulses are applied to the tube simultaneously.

COLINEAR ARRAY—An antenna having a string of ½ wavelength elements excited in phase.

COLLECTOR—An electrode in a velocity modulated vacuum tube on which the spent electron bunches are collected. It serves approximately the same purpose as the plate in a more conventional tube.

COLOR CODE—The system of colors used to specify the electrical value of a radio part or identify terminals and leads.

COMBINER—Circuit for mixing video, trigger and scan data from synchronizer for modulation of link.

COMPASS BEARING—Bearing measured relative to magnetic north.

COMPASS ERROR—Angle between N-S compass line and true meridian.

COMPASS TRANSMITTER (FLUX GATE)—Contains the Flux Gate, the sensitive element of the Gyro Flux Gate Compass System, which picks up the directive force of the earth's magnetic field.

COMPUTER—An instrument for calculating various quantities such as range, speed, altitude, etc., from the information supplied.

CONCENTRIC CABLE—See *Coaxial Cable.*

CONICAL SCANNING—A type of antenna beam scanning in which the tilt angle is fixed so that the axis of the r-f beam generates a cone whose vertex angle is usually from 5 to 10 degrees.

CONSOLE—Main operating unit of a radar in which indicators and general controls are installed.

CONTAMINATION—Deposition of cathode emitting material on grid of tube causing unwanted grid emission.

CONTINUITY TEST—An electrical test to determine the existence of a broken connection.

CONTROL—A knob, dial, switch or screw driver adjustment for operating an electrical installation.

CONTROL CENTRAL—See *Timer.*

CONTROL GRID—That electrode in a vacuum tube on which the signal is usually impressed. The control grid is the electrode nearest the cathode.

CONTROL PANEL—A panel where switches, potentiometers, meters, etc., are installed for controlling and protecting electrical equipment.

CONTROL TRANSFORMER—See *Synchro Control Transformer.*

CONVERSION GAIN OF THE CRYSTAL—The ratio of the available i-f power output to the available r-f power input. Is always less than unity.

CONVERTER—See *Mixer.*

CONVERTER UNIT—A unit of a radar system in which is located the mixer of a superheterodyne receiver, and usually two stages of i-f amplification. The converter unit usually is placed relatively close to the radar antenna. See *Pre-amplifier* (2).

COPPER OXIDE RECTIFIER—A rectifier made up of copper discs coated on one side with cuprous oxide. The cuprous oxide-copper discs have a unidirectional current characteristic, that is, they allow current to flow in only one direction. One common use is to obtain a-c voltage readings on a d-c instrument.

CORNER REFLECTOR—A device made in the form of three planes mutually perpendicular—as the three sides of a cube that meet at a corner. It is very effective in returning a strong radar echo.

CORONA—A luminous discharge due to ionization of the air surrounding a conductor around which exists a voltage gradient exceeding a certain critical value.

COSECANT SQUARED BEAM—A radar beam pattern designed to give approximately uniform signal intensity for echoes received from distant and nearby objects. Such a beam is generated by a spun barrel reflector. The beam intensity varies as the cosec^2 of the elevation angle.

COUNTER CIRCUIT—Receives uniform pulses representing units to be counted and produces a voltage in proportion to their frequency.

COUNTERMEASURES—See *Radar Countermeasures.*

'COUNTING DOWN' CIRCUIT—See *Frequency Divider.*

COUPLING—The means by which signals are transferred from one electrical circuit to another. Coupling can be direct through a conductor, capacitive through a capacitor, or inductive through a transformer, or any combination of these.

CROSS-LEVEL ANGLE—The angle between the plane of the ship's deck and a horizontal plane, measured in the plane perpendicular to the side of the level angle lying in the ship's deck. This quantity is positive if the right side of the deck, as seen by an observer facing the target, is raised. See *Level Angle.*

CRT—Cathode-ray tube.

CRYSTAL—(1) An electrically conductive, or semi-conductive mineral which has the property of rectifying small high frequency voltages. It is used as a detector or mixer in certain receivers.

(2) A plate of quartz or other material demonstrating a piezo-electrical characteristic. When properly combined with other electrical parts it will generate a voltage when mechanically stressed. It can be used to produce radio frequency oscillations and when put to this use has a very stable frequency characteristic.

CRYSTAL "BURN-OUT"—The impairment of a crystal by exposure to excessive r-f power.

CRYSTAL CHECK—Measurement of forward and backward crystal resistance.

CRYSTAL DETECTOR—A system composed of a metal wire and a crystal, which offers a higher resistance to currents in one direction than to currents in the other direction.

CRYSTAL MIXER—A housing containing the crystal, inputs for signal and local oscillator, and i-f output. Used in heterodyne detection for converting the received radar signal to a lower frequency before amplification.

CRYSTAL OSCILLATOR—An oscillator circuit using a quartz crystal or the mineral tourmaline and which depends for its operation on the principle of piezoelectricity. The quartz crystal exhibits the properties of a very high Q circuit when properly cut, which determines the frequency of oscillation and establishes a high order of frequency stability.

CRYSTAL-VIDEO RECEIVER—A broad-tuning receiver consisting of a crystal detector and a high-gain video amplifier. Usually an intercept receiver.

CURDIO—Current conditions of radio propagation conditions.

CURSOR—See *Bearing Cursor.*

CURSOR TARGET BEARING—Target bearing as measured by a PPI cursor.

CUTLER FEED—A resonant cavity at the end of a waveguide, which feeds r-f energy to the reflector of the spinner assembly.

CUT-OFF—(1) Value of grid bias required to reduce plate current to zero. (2) The longest space wavelength which can be conducted down any given waveguide.

CW-DOPPLER—Comparison of transmitted and echo frequencies to give an aural indication of moving target. No range information is provided; rate information available only when a single target is in the beam.

CW-OFF-CCW—A control. Rotation clockwise; off; rotation counter-clockwise.

CYCLE—In periodic phenomena, one complete set of recurring events.

D INDICATOR—A type of radar indicator which combines types B and C indicators. The signal appears as a bright spot with azimuth angle as the horizontal coordinate and elevation angle as the vertical coordinate. Each horizontal trace is expanded slightly vertically by a compressed time sweep to facilitate separation of signal from noise and to give a rough range indication.

DAMPING DIODE—A vacuum tube which damps the positive or negative half cycle of an a-c voltage.

DARK TRACE TUBE—A cathode-ray tube with a screen composed of a halide of sodium or potassium. The screen normally is nearly white, and wherever the electron beam strikes, it is tuned a magenta color which is of long persistence. The screen can be illuminated by a strong light source so that the reflected image may be made intense enough to be projected.

DB—Decibel.

DC—Direct current. Unidirectional current.

D.C.—INSERTION—See *Clamping Circuit.*

D.C. RESTORER—See *Clamping Circuit.*

DEAD SPOT—An area within or from which little or no signal is received.

DEBUG—To clear away the difficulties arising from improper design or construction of a set, and so to make it operate satisfactorily.

DECEPTION—The deliberate production of false or misleading echoes on enemy radars by the radiation of spurious signals synchronized to the radar, or by the reradiation of the radar pulses from extraneous reflectors. Small targets may be made to appear like large ones, or echoes may be made to appear where no genuine target exists.

DECIBEL (DB)—A unit used for comparing the power levels of two signals or of a signal to a fixed reference level of power. Also, a measure of power, current, or voltage gain.

DECK-TILT CORRECTION—When the spinner base is tilted with respect to the horizontal, changing the elevation of the reflector causes a small rotation about a true vertical axis. Thus a bearing error is introduced since bearing is read directly from the rotation of the spinner base. Removal of this error is called the deck-tilt correction.

DECODER—Unit made up of circuits for separating triggers, video, scan data, etc., as received over link from synchronizer.

DECONTAMINATE—The process of restoring the original condition of low emission to the grid of contaminated oscillator tubes in radar equipment. The remedy is effected by heating the grid to a white heat which is sufficient to boil the contaminating material from the surface, and yet not sufficiently hot to melt the grid.

DECOUPLER—Circuit for eliminating the effect of common impedance coupling. Main use is in power supply or measuring circuits to isolate signal circuit from supply.

DECOY—A reflecting object used in radar deception, such as a spar buoy that looks like a periscope, a group of streamers hung from a captive balloon, etc.

DEFLECTION COILS—Coils placed about the yoke of a magnetic cathode-ray tube to cause the displacement of the electron stream by the magnetic field produced within the tube as the result of current flowing in the coils.

DEFLECTION PLATES—Two pairs of parallel plates with each pair set at right angles to one another and parallel to the axis of the electron stream in an electrostatic cathode-ray tube. They are used to cause the displacement of the electron stream by the electric field produced between each pair.

DEFLECTION SENSITIVITY—In a cathode-ray tube, the ratio of the displacement of the electron beam at the point of impact to the change in the deflecting field. It usually is expressed in millimeters per volt applied between the deflection plates, or in millimeters per gauss of the deflecting magnetic field.

DEGENERATION—Feeding back into an amplifier a signal of polarity opposite to that of the input signal. This system reduces the overall gain of the amplifier but increases stability. It improves frequency response and lowers distortion.

DEHYDRATING UNIT—Used for removing moisture from the air supplied to radar transmission lines or enclosures.

DE-ICER—Heating circuit to melt ice from antenna assembly.

DELAY CIRCUIT—A circuit, usually a multivibrator, which introduces a time delay in passage of pulse or signal from one part of a circuit to another.

DELAY LINE—An artificial transmission line used to introduce a small time delay.

DELAY UNIT—A unit of a radar system in which pulses may be delayed a controllable amount. Used in providing expanded indicator presentations, etc.

DELAYED PPI—A plan position indicator in which the start of the sweep is delayed a variable or a fixed time after the PPI trigger, allowing distant targets to be displayed on a short range scale that provides an expanded presentation.

DELTA (Δ)—Greek letter usually indicating a small quantity or small change in a large quantity.

DEMODULATION—The process of obtaining the modulating component of a modulated radio wave.

DEPRESSION—Sensitivity-Time Control adjustment of initial gain at zero range.

DESICCANT—The chemical contained in a desiccator. Silica Gel.

DESICCATOR—Small units containing a chemical which absorbs water from the air. Used to keep the air inside of a piece of equipment dry.

DESTRUCTOR—See *Detonator.*

DETECTION—See *Demodulation.*

DETECTOR—That stage in a receiver at which demodulation takes place.

DETONATOR—A small unit containing a charge of some explosive used to damage the interior of a piece of equipment so that the enemy cannot use or reconstruct the equipment, should it fall into his hands. Sometimes called *destructor.*

DEVIATION ALARM—Unit which gives warning indication when synchro error exists due to failure of excitation, amplifier, etc.

DG SYNCHRO AMPLIFIER—Synchro differential generator driven by servo system. Generally used with OSC servo or deck tilt correction.

DF—Generally refers to radio direction finders. Is also sometimes used by the British for radar instead of RDF. Sometimes written *D/F.*

DG—Synchro differential generator.

DIAL LIGHT—Illumination of bearing scale.

DIELECTRIC—An insulator; a term applied to the insulating material between the plates of a capacitor.

DIFFERENTIAL SYNCHRO—See *Synchro Differential Generator* and *Synchro Differential Motor.*

DIFFERENTIATING CIRCUIT—A circuit which produces an output voltage substantially in proportion to the rate of change of the input voltage or current. Differentiating circuits employ time constants that are short compared to the duration of the pulse applied.

DIFFRACTION—Deviation of rays of a wave motion from a straight course when partially cut off by an obstacle or passing near the edges of an opening, or through a small hole. Its effect is more marked as wavelength increases.

DIMMER—Control for varying the intensity of illumination on pilot, scale, or dial lights.

DIODE—An electronic vacuum tube in which two elements—cathode and anode or plate—are used. Used for rectifying alternating voltages.

DIODE CLIPPER—A two-element vacuum tube and associated biasing circuit which can be adjusted to remove any unwanted portion, positive or negative, of a signal. See *Clipper.*

DIODE MIXER—A diode in r-f line which mixes incoming radio frequency and local oscillator signals to produce an intermediate frequency. See *Mixer.*

DIODE RECTIFICATION—Half-wave rectification by means of a diode which depends on the fact that a diode passes current in one direction only.

DIPLEXER—(*Not Duplexer.*) Permits the same antenna system to be used simultaneously or separately by two transmitters.

DIPOLE ANTENNA—Two metallic elements, each approximately ¼ wavelength long, which radiate the r-f energy fed to them by the transmission line.

DIPOLE DISK FEED—An antenna consisting of a dipole near a disk, which is used to reflect energy to the dish.

DIRECT CURRENT (DC)—Unidirectional current.

DIRECT WAVE—The component of the ground wave that is transmitted directly from transmitter to receiver. See *Sky Wave.*

DIRECTIONAL ANTENNA—Any antenna system or array which either receives or radiates r-f energy more efficiently in one direction than in any other.

DIRECTIONAL COUPLER—Wave guide coupling device to permit measurement of direct wave or incident power. Also provides coupling for echo box.

DIRECTOR—A parasitic element which reinforces radiation on a line pointing to it from the antenna.

DISCRIMINATOR—(1) Radar: A circuit that produces a response which depends on the frequency of the input signal. Used in AFC circuits. (2) Beacon: A circuit which accepts pulses of proper duration and rejects others.

DISH—A paraboloidal antenna reflector.

DISPLAY—A CRT screen and dials which present the information obtainable by the radar set; for example, range, bearing, elevation.

DISTANCE—See *Range.*

DISTRIBUTED CAPACITANCE—Capacitance between circuit elements or between tube elements, as distinguished from a lumped capacitance or capacitor. Also the capacitance of a transmission line per unit length of line.

DOORKNOB TUBE—The Western Electric 316A triode tube or other of similar shape designed for u.h.f. use. Resembles a doorknob in shape.

DOUBLE BOUNCE CALIBRATION—A method of calibration used to determine the zero set error by using round-trip echoes. The correct range is the difference between the first and second echoes. See *Radar Maintenance Bulletin,* page MK 3/4 5-12.

DOUBLE-DIODE LIMITER—A special type of limiter, which is used to remove all positive signals from a combination of positive and negative pulses, or to remove all the negative signals from such a combination.

DOUBLE-LAYER PHOSPHOR—Phosphor compound of 2 layers e.g., (1) zinc sulphide activated with silver, and (2) a mixture of zinc sulphide and cadmium sulphide activated with copper. Layer 1 emits short persistent blue light from electron impact, and layer 2 receives the blue light and converts it to yellow light of longer persistence. Used on *Long Persistence Screens.*

DOUBLE MODING—Frequency jumping, changing abruptly from one frequency to another, at irregular intervals.

DOUBLE STUB TUNER—An impedance matching device for a transmission line, consisting of two adjustable length stubs spaced a fixed distance apart.

DOUBLET TRIGGER—A trigger signal consisting of two pulses spaced by a fixed amount for coding.

DOUBLE-TUNED STAGE—A stage of the i-f strip of a receiver which has two coupled tuned circuits. Double tuned stages at present are tuned synchronously (in line) and ordinarily are critically coupled.

DRIFT—The change of frequency in an oscillator during warm-up period.

DRIVEN ELEMENT—An element which receives power from the transmitter through the transmission line.

DRIVER—(1) The circuit in the transmitter which produces a pulse to be delivered to the control grid of the modulator tube. (2) A unit driving another unit, as PPI Driver, etc.

DROOLER—A circuit which distorts a square type of pulse by reducing the sharpness of leading and trailing edges, and tending to round the top of the pulse.

DROP-BAR—A protective device used to ground a high voltage condenser when opening a door.

DROPPING RESISTOR—A resistor connected in a circuit which uses up a part of the voltage, thus leaving less voltage for the remainder of the circuit.

DRT—Dead Reckoning Tracer. A mechanical device on which a moving spot of light, or "bug," automatically indicates the approximate geographical position of own ship. The direction of motion of the bug is controlled by synchro data from the gyro compass, and the rate of motion is controlled by either the pitometer log or the dummy log.

DUMMY LOAD—A device in which the output power can be absorbed, used for simulating conditions of operation for test purposes. Usually a load to simulate an antenna. Also called *Dummy antenna* and *Sand load.*

DUPLEXER—A coaxial-line device consisting of a *Protective Tank* for the purpose of protecting the receiver from the transmitted pulse, and a *Decoupling Tank* used to keep the echo out of the transmitter. Use *TR* and *ATR* for microwave device of same nature. Sometimes called *Reprod.*

DURATION—A control for adjusting the time duration of reduced gain in Sensitivity-Time Control circuit.

DUTY CYCLE—The ratio of pulse length to pulse interval. Usually expressed in per cent.

DUTY CYCLOMETER—A test meter which gives direct reading of duty cycle.

DUTY FACTOR—The ratio of pulse interval to pulse length. Reciprocal of duty cycle.

DYNAMOTOR—A rotating piece of machinery having a d-c motor and a d-c generator on the same shaft. Low voltage d-c is supplied to drive the motor. This rotation causes the generator to generate a higher d-c voltage.

DYNATRON—Oscillator which makes use of negative plate resistance of a tetrode caused by secondary emission from the plate. Not the same as Transitron which is a negative transconductance oscillator not dependent on secondary emission.

DYNODE—Elements of electron multiplier or storage tube.

E INDICATOR—A modification of type B radar indicator. The signal appears as a bright spot with range as the horizontal coordinate and elevation as the vertical coordinate.

E UNITS—See *Radar Signal-Noise Ratio.*

ECCLES-JORDAN CIRCUIT—A direct-coupled multivibrator circuit possessing two conditions of stable equilibrium. Also known as a *flip-flop circuit.*

ECHO—The signal reflected by a distant target to a radar set. Also the deflection or indication on the screen of a cathode-ray tube representing a target.

ECHO BOX—A high Q resonant cavity which receives r-f energy through a pickup during the transmitted pulse and reradiates this energy through the same pickup immediately after the pulse. The reradiated energy is picked up by the radar set. Since the energy from the echo box dies off exponentially, it will appear on an A-scope indicator as a flat-topped pulse, resulting from the saturation of the receiver by the high energy return, followed by an exponential curve. The time from the end of the transmitted pulse to the point at which the echo-box signal is lost in noise is called the "ringing time" of the echo box. The echo box may be used to demonstrate graphically on the PPI scope the form of the antenna pattern, and to test the overall performance of the radar set.

ECHO BOX ANTENNA—A small dipole supported on a bracket near the radar antenna, used to pick up the radar pulse and to feed the echo box oscillations back to the radar antenna.

ECHO SUPPRESSION—IFF control used to disable the responsor for a short time to prevent reception of echoes from nearby targets that are produced by the interrogator pulse.

EEI—Expanded elevation indicator.

ELECTRIC FIELD INTENSITY—Property of a radio wave measured in terms of the e.m.f. it produces, e.g., if 20 microvolts are generated between the ends of a conductor 1 meter long when the radio wave cuts across it, the field intensity is said to be 20 microvolts per meter.

ELECTRICAL RESOLVER—A special type of synchro in which a single winding is put on the stator and two windings whose axes are 90° apart on the rotor.

ELECTRODE—A terminal at which electricity passes from one medium into another.

ELECTROMAGNETIC ENERGY—Forms of radiant energy found, for example, in radio waves, heat waves, light waves, X-rays, gamma rays, and cosmic rays.

ELECTROMAGNETIC FIELD—The portion of space in which the energy radiated in a radio wave can be detected. The field of energy always consists of a moving magnetic field and a moving electric field that act at right angles to each other. The direction in which the field moves is perpendicular to the line of action of both components of the field.

ELECTRON—The negatively charged particles of matter. The smallest particle of matter.

ELECTRON EMISSION—The liberation of electrons from an electrode into the surrounding space.

ELECTRON GUN—A group of electrodes in a vacuum tube, most commonly a cathode-ray tube, used to produce an electron beam of controllable intensity and to focus this beam to a small spot. This gun consists of a cathode and heater combination from which electrons are emitted thermionically, a grid for controlling the number of electrons that flow in the beam and hence the brightness of the luminous spot on a cathode-ray tube screen, and a means of focusing the beam.

ELECTRON MULTIPLIER—A vacuum tube in which electrons liberated from a photo-sensitive cathode when light strikes it are attracted successively to a series of electrodes, called dynodes. Each electron liberates others as it strikes each dynode, causing a great increase, or multiplication, in the number of electrons flowing in the tube. Amplification on the order of 1,000,000-fold is possible with such an arrangement.

ELECTRONIC INSTRUMENT—An instrument which utilizes for its operation the action of an electronic (thermionic) tube.

ELECTRONIC COUPLING—The method of coupling electrical energy from one circuit to another through electron flow in a vacuum tube.

ELECTRONIC SWITCH—A vacuum tube used as an on-off switch in some channel.

ELECTRONICS—That branch of science and technology which relates to the conduction and control of electron flow through gases or in a vacuum.

ELEVATION—Angular position in a plane perpendicular to the earth's surface. The horizon is usually minimum elevation and the zenith is maximum elevation. It is usually expressed in degrees. That is, the horizon is 0° and the zenith is 90°. It is occasionally expressed in mils, 0° being equal to 0 mils and 90° being equal to 1600 mils.

ELLIPTICALLY POLARIZED WAVES—Result from the superposition of two plane-polarized wave systems which are propagated in the same direction and have the same wavelength or frequency.

EMERGENCY—NORMAL—A control used to select the source of antenna training power.

EMERGENCY—OFF—A control not normally intended to turn off system power.

EMF—Electro-motive force. (Voltage.)

END-FIRE ARRAY—A directional antenna system designed to give the maximum radiation in a single direction lying in the plane of the array (e.g., Yagi array).

ERROR—(1) Error voltage in servo control or training. (2) Error in synchro bearing.

E-WAVE—A "mode" in which electromagnetic energy can be transmitted in a wave guide. An E-wave is a wave in which the magnetic field in the tube is everywhere transverse, i.e., perpendicular to the length of the tube, but in which the electric field in addition to having a transverse component, also has a longitudinal component parallel to the length of the tube. Also called a TM-wave.

EVASION—Tactics that are designed to take advantage of the limitations of radar to prevent or postpone radar detection, or to avoid revealing the true position of an attacking force.

EXPANDED SWEEP—(1) A sweep in which the movement of the electron beam across the screen is speeded up during a selected portion of the sweep time. See *R Indicator*. (2) In fire control radar, a range scale shorter than the longest scale provided, but extending from zero range rather than having its part delayed, as the precision sweep is. See *Precision Sweep*.

EXPONENTIAL SWEEP—A sweep whose speed varies exponentially with time. The sweep starts fast and decreases in speed as it approaches the end.

F INDICATOR—A type of radar indicator in which a single signal appears as a bright spot. Azimuth angle error appears as the horizontal coordinate, and elevation angle error as the vertical coordinate. Cross-hairs on the indicator face permit bringing the system to bear on the target.

FACE—The front or viewing surface of a cathode-ray tube. The inner surface of the face is coated with a material which gives off light under the impact of a stream of electrons.

FADE CHART—A graph on which the null areas of an air-search radar antenna are plotted as an aid to estimating target altitude.

FANNING BEAM—A narrow antenna beam which is repeatedly scanned over a limited arc.

FAST TIME CONSTANT (FTC)—A type of coupling circuit used in radar receivers to permit discrimination against echo pulses of duration longer than the transmitted pulse.

FEED—Means of supplying to the antenna the energy carried by the r-f line.

FEEDBACK—Transfer of energy from one point in an electrical system to a preceding point, such as from the output back to the input. See *Regeneration* and *Degeneration.*

FEEDBACK TIME CONSTANT—The time constant of an RC combination introduced into a circuit to determine the amount of delay in the feedback circuit. Determines also that the feedback is of the proper phase.

FERRET—An aircraft fitted with RCM equipment to be used in radar reconnaissance. U. S. Army term.

FIDELITY—Refers to width of video or audio response, which in turn determines the accuracy with which the input is reproduced in the output.

FIELD—Magnetic field of motors, generators, etc. See *Electromagnetic Field* or *Magnetic Field.*

FILAMENT—Directly heated cathode of a vacuum tube.

FILTER—Any combination of resistance, inductance, and capacitance which presents a low impedance to a certain frequency or group of frequencies, and at the same time presents a high impedance to other frequencies or to d-c.

FILTER, BAND PASS—A filter so designed that it tends to pass a band of frequencies and attenuates all frequencies outside of the band.

FILTER CHOKE—A coil of high inductance used to suppress more or less completely the alternating current components in the output of a rectifier.

FILTER, HIGH PASS—A filter so designed that it tends to pass all frequencies above a certain frequency and attenuates all frequencies below that frequency.

FILTER, LOW PASS—A filter so designed that it tends to pass all frequencies below a certain value and attenuates all frequencies above a certain value.

FINE—Refers to control for fine adjustment of tuning, intensity, etc.

FIRE—In a gas tube, to ionize, i.e., to become conducting.

FIRE CONTROL RADAR—System providing highly accurate range, bearing, and elevation data to fire control computers.

FIXED-FREQUENCY IFF—A class of IFF equipment which responds immediately to every interrogation, thus permitting the response to be displayed on plan position indicators. Compare *A-Band* and *G-Band.*

FIRST DETECTOR—See *Mixer.*

FIXED-TUNED—A circuit which is permanently tuned to a certain frequency.

FLASH PULSING—Transmission of short bursts of radiation at irregular intervals by a mechanically controlled keyer.

FLAT—Sensitivity-Time Control adjustment of maximum depression of gain.

FLAT LINE—An r-f transmission line, or part thereof, having a low standing wave ratio.

FLICKER—A random mode jump or breakdown condition observed in certain magnetrons, as a result of which the tube gives no power for one or two pulses at the prescribed frequency. The occurrence of this condition is random and varies from a very low rate to more than ten times per second, for different tubes.

FLIP-FLOP MULTIVIBRATOR—See *Start-Stop Multivibrator.*

FLUORESCENCE—The property of emitting light as the immediate result of electronic bombardment.

FLUORESCENT SCREEN—The thin coating of chemical material on the face of the cathode-ray tube. This material is chosen for its ability to transform electron energy into visible light. When the screen is bombarded by high velocity electrons, light is given off. The color of light emitted is dependent on the type of material used on the screen.

FLUXGATE—The magnetic azimuth-sensitive element of the fluxgate compass system which is activated by the earth's magnetic field. It is maintained in a horizontal plane by stabilizing it on an electrically-driven horizon gyro.

FLUXGATE AMPLIFIER—Amplifies the induced rotor voltages of the coupling synchro in the master indicator, and thus provides sufficient energy to drive the induction motor. Also contains oscillators for Flux Gate, and for the induction motor.

FLUX-GATE COMPASS—A gyroscope-stabilized compass used for supplying stabilization information concerning the geographical orientation of the PPI pattern. A "lubber line" produced on the PPI indicates the plane's heading once each rotation of the sweep. Consists of the following units: a Gyro-Stabilized Flux Gate Transmitter, an Amplifier, a Master Indicator, and from one to six Magnesyn (synchro) Remote Indicating Repeaters.

FLUXMETER—An instrument for measuring the intensity of a magnetic field.

FM DOPPLER—A type of radar involving frequency modulation of both carrier and modulation. For example, carrier frequency modulated 200 kc by a sine wave which is swept at a low rate between 0.5 to 10 kc. Range, bearing, and rate direction are indicated by left-right deflection on radial sweep.

FOCUS—In the cathode-ray tube, making appropriate electrical adjustments so as to give a sharp image of sweep line or signals on the face of the tube.

FOCUSING ANODE—One of the electrodes in a CRT, the potential of which may be varied to focus the electron beam. Varying the potential changes the electric field and thereby alters the path of the electrons to change the spot size.

FOE—Designation light to indicate foe on IFF.

FORDIO—Forecast conditions of radio propagation conditions.

FOUR-AXIS STABILIZATION—See *Stabilization.*

FRAMING—Shifting of pulses on trace.

FREE-RUNNING MULTIVIBRATOR—A multivibrator so arranged that it does not need a trigger pulse to start operation. Application of filament and plate voltages is all that is required.

FREQUENCY—The number of cycles per second which an electric current, a sound wave, or a vibrating object completes.

FREQUENCY CONVERTER—A circuit or device which changes the frequency of an alternating current. See *Detector* and *Mixer*.

FREQUENCY DISTORTION—Exists when all the frequency components of an input voltage are not amplified to the same degree.

FREQUENCY DIVIDER—A circuit or device designed to divide a frequency to a submultiple of that frequency.

FREQUENCY MODULATION—A system of modulation in which the deviation in frequency above and below the mean, or carrier frequency, is at each instant proportional to the amplitude of the signal being transmitted, and the number of complete deviations per second above and below the mean or carrier frequency is equal to the frequency of the signal being transmitted. Phase and amplitude remain constant.

FREQUENCY PULLING—Small changes in frequency of an oscillator caused by changes in load impedance.

FREQUENCY RESPONSE—The measure of the effectiveness with which a circuit or device transmits the different frequencies applied to it.

FREQUENCY SCANNING—Type of system in which output frequency is made to vary at a mechanical rate over desired frequency band.

FREQUENCY SPLITTING—One condition of operation of a magnetron which causes rapid alternating from one mode of operation to another. This results in a similar rapid change in oscillatory frequency and a consequent loss in power at the desired frequency.

FRIEND—Designation light to indicate friend on IFF.

FRONT-TO-BACK RATIO—The ratio of the resistance of a crystal to current flowing in the normal direction to the resistance to current flowing in the opposite direction. A term used in connection with checking crystals used as mixers in microwave receivers.

FTC—Fast Time Constant video coupling.

FUSE—An overcurrent protective device. Consists of a wire or strip of fusible metal inserted in a circuit. The strip melts when the current becomes too large.

FUSE ALARM—Light which indicates blown fuse.

G BAND—A frequency band used in Mark III IFF. Transpondors that operate in this band are fixed-tuned, so that immediate responses are obtained which can be displayed on a PPI. See *A-Band*.

G INDICATOR—A type of radar indicator in which a single signal only appears as a bright spot on which wings grow as the distance to the target is diminished. Azimuth angle appears as the horizontal coordinate, and elevation angle as the vertical coordinate. This has been referred to as the *Mark VI indicator* and as the *Spot Error Indicator*.

GAIN—(1) In an amplifier stage or system, the ratio of output voltage, current, or power to input voltage, current, or power. Often expressed in decibels. (2) In an antenna, a measure of the degree to which the radiation pattern becomes unidirectional. This is an important characteristic when it is desired to send as much energy as possible to one point only. It is given as the ratio of the energy density in the optimum direction to that from an equal source radiating isotropically.

GAP CODING—A means for inserting gaps, or periods of nontransmission, in a system that normally transmits continuously. The spacing and duration of the periods of silence from the code. System is used in some radar beacons.

GANG—To couple mechanically two or more variable components (capacitors, switches, and potentiometers) to facilitate operating from a single control knob.

GAP-MOTOR—Spark-gap modulator drive motor.

GASEOUS TUBE—An electronic tube into which a small amount of gas has been introduced.

GASSINESS (OF A TUBE)—The presence of gas in a vacuum tube, usually in relatively small amounts, due to leakage from outside, or evolution from the inside walls or elements of the tube.

GATE—A square voltage wave which switches a circuit on or off electronically; usually by application to a grid or cathode.

GATE-PRODUCING MULTIVIBRATOR—A rectangular-wave generator designed to produce a single positive or negative gate voltage when triggered and then to become inactive until the next trigger pulse.

GCA—Ground control of the approach of an aircraft to an airfield.

GCI—Ground control of interception. A technique that is accomplished by cooperation between a land-based radar set and fighter aircraft equipped with their own radar sets.

GCL—Ground control of the landing of aircraft.

GENERAL CONTROL UNIT—Remote control unit associated with operator's console which permits full control of all necessary operating functions.

GENERATOR—(1) A rotating machine which converts mechanical energy into electrical energy. (2) A radio device which develops an a-c voltage at a desired frequency and of a desired shape when energized with d-c power.

GETTER—An alkali metal introduced into a vacuum tube during manufacture and fired after the tube has been evacuated to react chemically with any gases which may have been left in manufacture. The silvery deposit on the inside of the glass envelope of a tube, usually near the tube base, is the result of getter firing.

GHOST SIGNALS—Signals appearing on the screen of the radar indicator, the source of which cannot readily be determined.

GL—Gun laying. Information supplied by GL equipment (range and bearing) is used to direct guns and to control their firing fire control radar equipment.

GLIDE PATH—A radar beam for blind or instrument landing of aircraft.

GONIOMETER—A device used in RDF for the comparison of signal amplitudes. It consists of two equal mutually perpendicular stator coils, having a common axis, and a rotor coil which rotates about this axis.

GMCM—Guided Missile Countermeasures.

GRASS—In radar, random interference caused primarily by circuit noise. The interference appears as sharp, closely spaced discontinuities in the base line of radar indicators. If the equipment is operating properly, the height of the grass is substantially level across the screen, and not sufficiently great to cause bad interference to echoes from targets within range.

GRID BIAS—See *Bias*.

GRID PULSING—A method of pulsing in which the oscillator is biased so negatively that no oscillations take place, even with full plate voltage applied, until application of positive keying pulse to grid.

GROUND—A conducting connection, whether intentional or accidental, between an electric circuit or equipment and earth, or to some conducting body which serves in place of the earth.

GROUND CLUTTER—Radar echoes reflected from terrain, which obscure relatively large areas of the radar indicator.

GROUND RANGE—The distance from an object on the ground to a point on the ground directly beneath an aircraft.

GROUND-REFLECTED WAVE—The component of the ground wave that is reflected from the ground.

GROUND RETURN—See *Ground Clutter.*

GROUND SPEED—The speed of an aircraft relative to the earth.

GROUND WAVE—The portion of a radio wave that is propagated through space and is, ordinarily, affected by the presence of the ground. The ground wave is somewhat refracted by the gradual change with altitude of the dielectric constant of the lower atmosphere.

GROUNDED-GRID TRIODE MIXER—A triode in which the grid forms part of a grounded electrostatic screen between the anode and cathode, and is used as a mixer for centimeter wavelengths.

GUIDE WAVELENGTH—The wavelength of electromagnetic energy conducted in a wave guide. The guide wavelength for all air-filled guides is always longer than the corresponding free-space wavelength.

GUIDED PROPAGATION—See *Trapping.*

GUILLEMIN LINE—The network used in high-level pulse modulation for generating a square pulse with steep rise and fall.

GYRO COMPASS—A type of compass in which the axis of a gyroscope is made to point constantly to geographic or true north. Also called the *Master Gyro Compass.* A synchro system is used to repeat the compass indications at suitable locations throughout the ship.

GYRO REPEATER—The indicator driven by the synchro system associated with the master gyro compass.

GYROSCOPE—An instrument which utilizes a rotating mass to maintain a stable equilibrium.

H INDICATOR—Intensity modulated signals on a CRT with range vertical and azimuth horizontal. Tangent of echo tilt angle proportional to sine of angle of elevation.

HALF WAVE ELEMENT—A conductor of such length as to be resonant at a given frequency.

HARMONIC—A multiple of any particular frequency.

H. CENTER—A control for adjustment of horizontal position of CRT pattern.

HARD TUBE—See *High-Vacuum Tube.*

HEADING—True or magnetic compass direction in which the ship or aircraft is pointed. Also called *Ship's head.*

HEATER—(1) Space heater for control of temperature and reduction of humidity. (2) Element of a vacuum tube which indirectly heats the cathode.

HEAVISIDE LAYERS—Layers of ionized gas, believed to exist in the region between 50 and 400 miles above the surface of the earth, which bend radio waves, of frequency below about 40 megacycles, back to earth under certain conditions. Also called the *Kennelly-Heaviside layer.*

HEIGHT—The vertical distance of the target above the horizontal plane through the point upon which the range keeper or data computer bases its solution. Usually measured in feet.

HELICAL SCAN—The scanning motion in which a point on the r-f beam describes a distorted helix. The antenna rotates in azimuth while the elevation angle changes from horizontal to vertical.

HELIPOT—Trade name for a potentiometer wound in a helical form so that the variable arm may make several revolutions.

HELMHOLTZ COIL—A phase-shifting network consisting of fixed and movable coils. With a constant input, fixed in phase, the output may be continually shifted in phase from 0° to 360°. Used to determine range in certain radar equipment.

HETERODYNE RECEPTION—Reception by combining received radio frequency with locally generated oscillations. Beat frequency may be audible or may be IF which is further amplified and demodulated. See *Superheterodyne.*

HF—High frequencies (3000 to 30,000 kilocycles).

HIGH PASS VIDEO (HVP)—Filter in video circuit used to permit only the higher frequency components of a signal to pass.

HIGH-VACUUM TUBE—A vacuum tube evacuated to such a degree that its electrical characteristics are essentially unaffected by gaseous ionization.

HIGH VOLTAGE—Refers to control, meter, rectifier, etc., for vacuum tube plate supply.

HOLLOW WAVEGUIDE—See *Waveguide.*

HOMING ANTENNA—A type of directional antenna array useful when it is desired to fly directly to a target.

HOOD—A shield placed over a CRT to eliminate extraneous light and thus make the image on the screen appear clearly.

HORIZONTAL POLARIZATION—Electric field (E vector) parallel to the horizon. An antenna in which the dipoles are horizontal is horizontally polarized.

HORIZONTAL SPOT LIMIT-LEFT (RIGHT)—Control of tracking spot on "B" Indicator.

HORN—A type of radiator or feed used to direct radiation from a wave guide.

HUNTING—Mechanical oscillation in a servo system due to improper adjustment of control voltage, servo amplifier, or feedback.

HVP—See *High Pass Video.*

H-WAVE—A "mode" in which electromagnetic energy can be transmitted in a wave guide. An H-wave has an electric field which is entirely transverse, i.e., perpendicular to the length of the wave guide, and a magnetic field which has a longitudinal component in addition to its transverse component. Also called TE waves.

I INDICATOR—A type of radar indicator used to depict range and direction for a system with a conically scanning antenna. The signal appears as a bright circular segment with radius proportional to range. The circular length of the segment is inversely proportional to the error of aiming the system, and its position indicates the bearing of the target. True aim results in a complete circle. This has been referred to as *RTB Indication* and as *Broken Circle Indication.*

IAVC—Instantaneous Automatic Volume Control. A radar receiver circuit which uses the echo amplitude of each returning signal to vary the receiver gain. The action of the circuit is delayed for a time approximately equal to the pulse duration so that echoes from isolated targets are not affected. However, if signals are received continuously for a period longer than the pulse duration, the receiver gain is decreased, but it returns to normal shortly after the end of this longer signal.

ICONOSCOPE—A cathode-ray tube with a photo-mosaic and scanning electron beam which converts a visible image into fluctuating electrical currents. Used as a camera tube in television.

IF—Intermediate frequency.

IFF—Identification, Friend, or Foe. Generic term applied to systems or equipment used for the recognition of ships or aircraft detected by radar.

IFF COORDINATOR—Unit for coordination of IFF Trigger, Range Indicator Trigger and Radar and IFF displays on "A" Indicator.

IDENTIFICATION—The process of indicating your own friendly character. See *Recognition.*

ILLUMINATION—Lights for meters, range dials, bearing dials, etc. Also refers to radar beam being directed on a target.

IMAGE FREQUENCY—An undesired signal capable of beating with the local oscillator signal of a superheterodyne receiver which produces a difference frequency within the bandwidth of the i-f channel.

IMPEDANCE—The total opposition which a radio part or circuit offers to the flow of alternating current at a particular frequency. Impedance is a vectorial combination of resistance and reactance and is measured in ohms.

IMPEDANCE MATCHING—See *Matching.*

IMPEDANCE TRANSFORMER—An impedance matching device used to provide a maximum transfer of energy from one circuit to another.

INCIDENT—Refers to a wave travelling in a direction toward the load.

INDICATOR—That component of a radar set by which the data obtained by the set is presented for visual observation.

INDUCTANCE—That property of a circuit which tends to oppose any change in current. Inductance is effective only when varying or alternating currents are present; it has no effect on direct current of constant amplitude.

INDUCTIVE COUPLING—A form of coupling in which energy is transferred by induction from a coil in one circuit to a coil in another circuit. Varying magnetic lines of force produced by the flow of varying direct current or alternating current through one coil causes an a-c voltage to be induced in the other coil.

INDUCTIVE KICK—Refers to the fact that when the current through an inductor is broken abruptly, the collapse of the magnetic field through the windings of the coil may generate across the coil a voltage many times higher than the impressed voltage.

INDUCTOR—A circuit element designed so that its inductance is its most important electrical property; a coil.

IN-LINE TUNING—Method of tuning the i-f strip of a superheterodyne receiver in which all the i-f amplifier stages are made resonant to the same frequency. This type of tuning results in a narrow i-f bandwidth. Compare *Stagger Tuning.*

INPUT (IN)—Used to indicate signal, power, trigger, etc., fed in to a unit or circuit.

INPUT IMPEDANCE—The impedance between the input terminals of a network.

INSTANTANEOUS AUTOMATIC VOLUME CONTROL—See *IAVC.*

INTEGRATING CIRCUIT—A circuit which produces an output voltage substantially in proportion to the frequency and amplitude of the input voltage. In a few special cases, the waveshape of the output is approximately the mathematical integral of the waveshape of the input.

INTENSIFIER ELECTRODE—An electrode provided in some types of electrostatic cathode-ray tubes which permits additional acceleration of the electron beam after it has been deflected. The advantage of this extra electrode is that it permits greater intensity of the trace without materially reducing the deflection sensitivity of the tube.

INTENSIFIER PULSE—A pulse or gate voltage used to turn a cathode-ray beam on and off at a specified time.

INTENSITY CONTROL—That control which, by varying the bias on a cathode-ray tube, controls the beam current of the tube and hence the amount of light generated by the fluorescent screen.

INTENSITY MODULATION—In a cathode-ray tube, causing the intensity of the light generated to vary in accordance with the modulating signal.

INTERCEPT RECEIVER—See *Search Receiver.*

INTERCEPTION—The detection of radar signals by use of a special receiver and associated apparatus.

INTER-ELECTRODE CAPACITANCE—The capacitance which exists between two electrodes in a vacuum tube. Although this is usually a very low value, it becomes extremely important in ultra-high frequency circuits. See *Distributed Capacitance.*

INTERFERENCE—Confusing signals accidentally produced on a radar indicator by the effects of either friendly or enemy electrical apparatus or machinery, or by atmospheric phenomena.

INTERLOCK—A safety switch which de-energizes high voltage when doors, access covers, or other openings are opened.

INTERMEDIATE FREQUENCY (I-F)—In a superheterodyne receiver, the frequency to which all incoming carrier frequencies are converted before being fed to the i-f amplifier. See *Local Oscillator.*

INTERMEDIATE FREQUENCY AMPLIFIER—That section of a superheterodyne receiver which is designed to amplify signals with high efficiency at a predetermined frequency called the intermediate frequency of the receiver.

INTERMITTENT PULSING—Transmission of short bursts of radiation at irregular intervals.

INTERMITTENT SCANNING—One or two 360° scans of antenna beam at irregular intervals to increase difficulty of detection by intercept receiver.

INTERROGATOR—A pulsed radio transmitter which emits signals on some frequency in the IFF band, and which is associated with the radar equipment whose echoes must be recognized.

INVERSE FEEDBACK—Intentional negative feedback or degeneration introduced in an amplifier or single vacuum tube stage for the purpose of reducing the distortion, increasing the stability, and improving the frequency response. See *Degeneration.*

INVERTED—Changed in sign, e.g., a positive voltage pulse is inverted to obtain a negative pulse.

INVERTER—(1) A polarity inverting amplifier. (2) A rotating machine acting both as motor and generator, used to change a d-c input voltage to an a-c output voltage.

IONOSPHERE—A body of ionized gas which exists in the outer portion of the earth's atmosphere. See *Heaviside Layers.*

IR—Interrogator-Responsor.

IRIS—A commonly used impedance matching device in a waveguide transmission line system. It consists of an aperture placed in a waveguide section. The relative size of the aperture with respect to the waveguide controls the effective electrical length of the section.

ISOLATION DIODE—A diode used to pass signals in one direction through a circuit, but to prevent signals from being transmitted in the opposite direction.

ISOTROPIC RADIATOR—A radiator which sends out energy equally in all directions.

J ANTENNA—A type of vertical ½-wave antenna, end fed by a ¼-wave matching stub.

J INDICATOR—A type of radar indicator which is a modification of type A indicator. The time sweep produces a circular range scale near the circumference of the cathode-ray tube face. The signal appears as a radial deflection of the time trace. No bearing indication is given.

JAMMING—Intentional transmission of r-f energy in such a way as to interfere with reception of signals by another station.

JITTER—Instability of signals or trace on a cathode-ray tube caused by variation in the synchronization of components, leading to variations in the position of the observed pulse along the sweep.

JUNCTION BOX—An enclosed distribution panel for connecting or branching one or more electric circuits without the use of permanent splices.

K INDICATOR—A modification of type A scan used for aiming a double-lobe system in bearing or elevation. The entire range scale is displaced in the direction of the antenna lobe in use. One signal appears as a double deflection from the range scale, and the relative amplitudes of these two pips serves as an indication of the error in aiming the antenna.

KEEP-ALIVE—An auxiliary electrode in the T-R tube, to which a negative d-c potential is applied. The keep-alive voltage is on continuously in order to furnish sufficient ions for almost instantaneous discharge across the main gap with small leakage power to the crystal.

KEEPER—A piece of magnetic material placed across the pole pieces of a permanent magnet to enable it to maintain its magnetic strength by providing a low reluctance path for the magnetic field.

KENNELLY-HEAVISIDE LAYERS—See *Heaviside Layers.*

KEYER—Name sometimes given to the modulator of a radar set.

KIDNEY JOINT—A flexible joint, or air-gap coupling, used in the waveguide of certain radars, and located near the transmitting-receiving position. The kidney joint, so called because of its shape, consists of two flanges facing each other but spaced ⅜ to ½ inch apart. The face of each flange extends about ¼ wavelength perpendicular to the waveguide and then has a skirt about a ¼ wave deep about the outside.

KILLER CIRCUIT—That vacuum tube or tubes and associated circuit in which is generated the blanking pulse used to temporarily disable a radar set. The circuit is usually triggered from a pulse obtained from another piece of radar equipment. This disabling is essential in order to eliminate interference arising from the use of two pulsing systems in close proximity to one another.

KILLER PULSE—See *Killer Circuit.*

KILO (K)—A prefix meaning 1,000, as kilocycle, kilowatt, etc.

KLYSTRON—A tube in which oscillations are generated by the bunching of electrons as the result of velocity modulation of the electron stream. This tube uses the transit time of the electrons between two electrodes as a means of controlling the delivery of pulsating energy to a cavity resonator in order to sustain oscillations within the cavity.

KNOCKER—A subassembly in radar equipment, comprising synchronizing and triggering circuits. The knocker is used to drive the r-f pulse generating equipment in the transmitter and to synchronize the cycle of operation in range units and range indicators with the transmitted pulse. Term is used only with some Fire Control radars.

L INDICATOR—A time sweep produces a vertical range scale and signal appears as left and right horizontal deflection of equal amplitude when target bearing is zero degrees relative.

LAB—Low altitude bombing.

LAND RETURN—See *Ground Clutter.*

LEAKAGE—(1) An undesirable flow of current through or over the surface of a dielectric material.

(2) That portion of a magnetic field which is not utilized most effectively. For example, the field appearing at end pieces of an electromagnet.

LEAKY WAVEGUIDE ANTENNA—An antenna constructed of a long waveguide with radiating elements at intervals along its length. It can be made to have a very sharp pattern.

LEVEL ANGLE—The angle between the horizontal plane and the deck plane measured in the vertical plane through the line of sight. (Positive when the deck toward the target is below the horizontal plane).

LF—Low frequencies (30 to 300 kilocycles).

LIGHTHOUSE TUBE—Parallel element tubes suitable as local oscillator or r-f amplifier, etc., in microwave region.

LIMITING—Removal by electronic means of one or both extremities of a waveform at a predetermined level.

LIMIT RATIO—Ratio of peak value to limited value, or comparison of such ratios.

LINE BALANCE CONVERTER—See *Bazooka.*

LINE PULSING—A method of pulsing a transmitter in which an artificial line is charged over a relatively long period of time and then discharged through the transmitter tubes in a short interval determined by the line characteristics.

LINE STRETCHER—An impedance matching device for coaxial transmission lines.

LINE VOLTAGE—Voltage level of main power supply to equipment.

LINEAR ARRAY—Single line of dipole antennas.

LINEAR SCAN—A radar beam which traverses one arc or circle only. For example, a beam which is oscillated back and forth over a 30° angle in the horizontal without being elevated.

LINEAR SWEEP—A periodic voltage, applied to the horizontal deflecting plates of the cathode-ray tube, which increases linearly with time up to a maximum value and then falls abruptly to zero. This causes the spot to sweep across the screen at a uniform velocity.

LINE OF POSITION—A locus of the possible positions of a ship.

LINE-OF-SIGHT—The straight line which joins observer and point of aim (on target).

LINE-OF-SIGHT COVERAGE—The distances to which radar and television sets are commonly said to be limited because the radiated waves do not follow the curvature of the earth. The horizon range based on the height of the antenna. Refraction effects on radar beams, similar to mirage effects observed with visible light, can take place under certain atmospheric conditions, resulting in greatly increased coverage. See *Trapping.*

LINE-OF-SIGHT STABILIZATION—See *Stabilization.*

LINEAR TIME BASE—See *Linear Sweep.*

LINK—Refers to radio link which transmits synchronized video, trigger, and scan data to remote decoder and repeater.

LISSAJOUS FIGURES—Patterns produced on the screen of a CRT by combination of sine wave signal voltages, of various amplitude and phase relations, on horizontal and vertical deflection plates.

LOAD DIVIDER—Unit for distributing regulated or unregulated power to various units.

LOAD SET—Adjustment of load relay.

L. O. INJECTION—An adjustment used to vary the magnitude of the local oscillator signal that is coupled into the mixer.

LOBE—Refers to the two or three dimensional polar representation used to indicate the distribution in space of antenna field strength intensities. The curve shows points of equal field strength, power, or voltage as desired.

LOBE PATTERN—See *Fade Chart.*

LOBE SWITCHING—Any method (electrical or mechanical) of alternately shifting the lobe of an antenna system from one direction to another. The difference in direction between the two or more positions is predetermined. It is used in conjunction with a receiver or indicator switching system to provide more accurate angular (bearing or elevation) position data.

LOCAL OSCILLATOR (LO)—An adjustable-frequency oscillator used in a superheterodyne receiver. The output of this oscillator is mixed with a desired r-f carrier to form a signal of lower, or intermediate, frequency.

LOCK—Indication of locking position of a control.

LOCKING—(1) Controlling the frequency of an oscillator by means of an applied signal of constant frequency. (2) Automatic following of a target by a radar antenna.

LONG PERSISTENCE SCREEN—A cathode-ray tube screen in which the phosphorescent characteristic of certain chemicals is utilized. Fluorescent and phosphorescent compounds are combined and bombarded with electrons. The fluorescent material translates electron energy to light and the phosphorescent material gives off additional amounts of light when the fluorescent light strikes it. The total effect is to provide a screen in which the decay time of the light is relatively long, usually several seconds.

LORAN—Long range navigation system. See *Ships* 278.

LORD MOUNT—A vibration insulating mount, made in two types: cup type and flush type shear mounts. Load ratings are from 1 to 90 lb. for both types, depending on application.

LOSSY LINE—A cable used in test measurements which has a large attenuation per unit length.

LOWER—Refers to voltage, gain, frequency, etc., adjustment.

LUBBER'S LINE—A prominent fixed line on the compass, drift sight, pelorus, or PPI made parallel to the ship's keel to furnish a reference for indicating ship's heading.

M INDICATOR—A modification of type A scan in which the horizontal time base is slightly displaced in a vertical direction by insertion of a step which serves as an adjustable range marker. A ranging circuit is used for controlling the position of the step along the trace, and range is indicated on counters when the step and an echo are brought into coincidence.

MAGNETIC CIRCUIT—A complete path for magnetic lines of force. It includes the magnet producing the lines of force.

MAGNETIC FIELD—The space occupied by continuous lines of force linking the north and south poles of a magnetomotive force.

MAGNETIC FOCUSING—A method of focusing an electron stream by which the electrons are brought to a point through the action of a magnetic field.

MAGNETIC LINES OF FORCE—Imaginary lines used for convenience to designate the direction in which magnetic forces are acting as a result of a magnetomotive force.

MAGNETRON—An ultra-high frequency oscillator tube. Because of its available high peak power it is often used as a transmitter tube in radar sets.

MAIN CONTROL UNIT—Unit associated with Transmitter-Receiver Unit containing controls not necessary to operator but essential for energizing, adjustment, etc.

MAIN POWER—Line power supplied to complete system.

MAIN SWEEP—On some fire control radars, the longest range scale available.

MAINTENANCE CONTROLS—Those necessary for correct setup of equipment and not available to operator.

MANUAL—Used with gain, train, tuning, etc. Operation by hand without using any other source of power.

MARKER—Electronic range or bearing indication on radar indicator.

MARKER OSCILLATOR—Source of range markers.

MASKING—See *Clutter.*

MASTER GAIN—Control of overall gain to all associated indicators.

MASTER GYRO COMPASS—See *Gyro Compass.*

MASTER MULTIVIBRATOR—A master oscillator using a multivibrator circuit.

MASTER OSCILLATOR—A timing oscillator which controls other circuits.

MASTER PPI—PPI unit associated with a system console.

MATCHING—Connecting two circuits or parts together with a coupling device in such a way that the impedance of either circuit will be equal to the impedance existing between the coupling terminals to which that circuit is connected.

MATCHING STUB—A device placed on an r-f transmission line which varies the electrical length of the line. The impedance of the line can be adjusted in this manner.

MATTRESS ANTENNA—Vertical or horizontal half-wave antennas arranged in rows, with the rows one above the other. A flat sheet-metal, expanded metal, or wire screen is used behind the array as a reflector.

MAXIMA (MINIMA)—The regions of maximum and minimum return from the transmitted pulse caused by additive and subtractive combinations of the direct and reflected waves. A plot of this data is usually known as a *Null Pattern* or *Fade Chart.*

MAXIMUM SET—A control for sweep calibration at maximum range.

McNALLY TUBE—A velocity modulated vacuum tube designed to produce low-power uhf oscillations. It is used as a local oscillator in some radar receivers.

MEGA (M)—Prefix meaning one million, as megacycle, megawatt, etc.

MEW—Microwave early warning radar. Gives long-range warning of approaching aircraft, and allows continuous plotting, in range and azimuth, of multiple targets. AN/CPS-1.

MF—Medium frequencies (300-3000 kilocycles).

MG—Motor generator.

MICRO—Prefix meaning one millionth, as microfarad, microsecond, etc.

MICROPHONIC NOISE—Noise caused by mechanical vibration of the elements of the tubes.

MICROSECOND—One millionth of one second.

MICRO-SWITCH—Trade name for a small switch which can be operated with very small pressure and very small displacement. They may be either normally open or normally closed.

MICROWAVES—Radio waves having wavelengths shorter than 50 centimeters.

MINIMUM SET—A control for sweep calibration at a low end of range scale.

MIRROR REFLECTION ECHOES—Multiple reflection echoes that are caused by the radar beam being reflected from a large flat surface, as the side of an aircraft carrier, and subsequently striking other nearby targets.

MIXER—The stage in a superheterodyne receiver in which the incoming modulated radio-frequency signals are mixed with the local oscillator signals to produce the intermediate-frequency signal. The mixer may be either a vacuum tube or a crystal. Also called *First Detector* and *Converter.*

MODE—Different types of electromagnetic waves that may be sustained in a given resonant system. Each type is designated as a particular mode and has its own electric and magnetic field configuration.

MODEL TERMINOLOGY—(1) *Experimental, Model Shop,* or *Breadboard Models* produced by manufacturer, at his expense, for establishing electrical performance. (2) *Developmental Model.* Manufactured under contract to establish new or radically revised specification. (3) *Preliminary Model.* Production contract for "hand-made" model to determine contractor's ability to meet established specifications. These are additional equipments over requirements. (4) *Preproduction Model.* Prototype of production and completely interchangeable. Considered and accepted as one of production equipments.

MODULATED WAVE—A radio frequency carrier which varies either in frequency or amplitude in accordance with the waveform of the modulating signal.

MODULATION—The variations in frequency or amplitude of an r-f carrier which contain the information or signal being transmitted. Also the process of modulating an r-f carrier.

MODULATION GENERATOR—See *Timer.*

MODULATOR—That component of a radar set which turns on and off (keys) the transmitter. The pulse width of the transmitter is controlled by the modulator.

MOMENTARY—Used with key switch for Radiation and Challenge operation. The circuits are active only while key is depressed, and they become inactive when the switch is let go.

MONITOR—A term used with meter, cathode-ray tube, antenna, receiver, etc., which are used to check the operation and performance of a system by examining a small part of the output.

MOTOR BOATING—Regeneration in an audio, video, or r-f amplifier causing a low-frequency oscillation and resulting in intermittent operation of the amplifier.

MOTOR-GENERATOR (MG)—Rotating machine used to convert ship power to form suitable for energizing system.

MTI—Moving Target Indication. See *CW, FM* and *Pulse Doppler.*

MULTIELEMENT PARASITIC ARRAY—An array of dipoles and parasitic reflectors, arranged so as to produce a radar beam of desired directivity.

MULTIPLE REFLECTION ECHOES—Echoes returned from a real target by way of reflection from some object in the radar beam. Such echoes appear at a false bearing and false range, and may therefore be very alarming in some circumstances.

MULTIPLE TRIP ECHOES—See *Second Trip Echoes.*

MULTIVIBRATOR—A form of relaxation oscillator, essentially a two-stage amplifier with feedback. Will oscillate of its own accord, or through an external synchronizing voltage.

N INDICATOR—A modified type A scan with two traces horizontally displaced to permit pip matching in a lobe-switching system, with a range step in each trace to permit direct measurement of range. A combination of types K and M scans.

NAUTICAL MILE—6080.27 feet (as contrasted with statute or land mile, 5280 feet). The length of one minute of arc of the equator. 6000 feet or 2000 yards is used in the Navy for all gunnery, navigation and radar applications. Standard frequency for calibration is 81.967 kc, since the time required for one cycle at this frequency equals the time required for a radio wave to go out to and return from a target 2000 yards away.

NEGATIVE FEEDBACK—See *Degeneration.*

NETWORK—Any combination of capacitance, inductance and/or resistance electrically interconnected.

NMP—Navigational Microfilm Projector. A device for superimposing on the PPI pattern the virtual image of a chart projected from microfilm. By changing the lens system, the scale of the projected chart can be altered to match either of two range scales on the radar indicator. See *VPR.*

NOISE—A random voltage appearing at the output terminals of a receiver with no impressed signal, if the amplifier has sufficient gain. It is due to random motion of electrons in the grid circuit of the first amplifier tube, to fluctuations in emission, shot noise at the plate, etc. On the A scope, noise appears as random spikes ("grass") on the sweep line.

NOISE FIGURE—The figure of merit for sensitivity of a receiver. Defined as the ratio of the input power to kTB (where k is Boltzmann's constant, T the temperature in degrees Kelvin, and B the bandwidth in cps) when the output signal power equals the output noise power. Noise figure normally is expressed in db.

NON-LINEAR COIL—A coil having an easily saturable core possessing high impedance at low or zero current and low impedance when current flows and saturates core. *Peterson Coil.*

NOTCH—Rectangular depression in sweep trace used as a range mark.

NULL—An area in the antenna pattern of a radar where the field strength is very low because of the interference between direct radiation and radiation reflected from the sea. The positions of the nulls are fixed by the geometry of the system; no kind of device put on the antenna can change the locations of the nulls.

O INDICATOR—A type A scan modified by the inclusion of a notch for measuring range.

OFF-CENTER PPI—A modified type of PPI presentation in which the center about which the sweep trace rotates can be moved off the face of the cathode-ray tube as a means of expanding the presentation in order to provide better resolution. The pattern is stabilized so that true north always remains at 12 o'clock on the screen.

OFF-ON—Circuit Control.

OMNIDIRECTIONAL—A type of antenna that radiates equally in all directions, insofar as technological limitations permit. Omnidirectional antennas are used primarily with IFF and radar beacons.

ON TIME—Adjustment of "on" period of multivibrator in some types of timing circuits.

ONE-AXIS STABILIZATION—See *Stabilization.*

ONE-CYCLE MULTIVIBRATOR—See *Start-Stop Multivibrator.*

ONE SPEED—A synchro system in which the rotor of the synchro generator turns one revolution for each revolution of the shaft whose position is to be reproduced remotely.

OPERATE—Position of a control that indicates normal operating condition.

OPERATIONAL CONTROLS—Those necessary for operation of equipment.

O.S.C. BUS—Own ship's course gyro supply. Voltages derived from synchro at master gyro compass.

O.S.C. EXCITATION—Own ship's course synchro excitation.

O.S.C. 1 SPEED—Own ship's course single speed synchro data. Synchro geared 1:1 to gyro compass.

O.S.C. 36 SPEED—Own ship's course 36-speed synchro data. Synchro geared 36:1 to gyro compass.

OSCILLATION—(1) A condition whereby alternating voltages are generated in a circuit. (2) One complete cycle of a periodically recurring phenomena.

OSCILLATOR—A vacuum tube and associated circuit which generates an a-c signal when d-c power is applied.

OSCILLATORY CIRCUIT—A circuit in which oscillations can be generated or sustained.

OSCILLOSCOPE—See *Cathode-Ray Oscilloscope.*

OUT (OUTPUT)—Used to indicate the signal, power, trigger, etc., fed out of a unit or circuit.

OUTPUT IMPEDANCE—The impedance between the Output terminals of a circuit measured at a definite frequency or at a predominant frequency in the range which the device is to handle.

OVER CURRENT RAISE—Relay adjustment.

OVERLOAD—Type of relay or adjustment.

OVERSHOOT—Excessive potential attained by a portion of the main body of a pulse.

OWN SHIP COURSE (OSC)—The direction prescribed for the ship's movement, or the direction in which the ship sails from one place to another.

P INDICATOR—See *PPI.*

PANORAMIC ADAPTOR—A special oscilloscope used with a search receiver to assist the RCM operator in interpreting the signals that are detected.

PAN-RANGIC—Intensity modulated "A" type of indication with slow vertical sweep applied to video. Stationary targets give solid vertical deflection and moving targets give broken vertical deflection.

PARABOLIC REFLECTOR—A metallic sheet formed so that its cross section is in the shape of a cylindrical parabola. The antenna elements are placed along the line that runs through the focal point of the parabola, parallel to the leading edge of the reflecting sheet. See *Paraboloid.*

PARABOLOID—A reflecting surface formed by rotating a parabola about its axis of symmetry. Paraboloidal reflector or dish.

PARAPHASE AMPLIFIER—See *Phase Inverter.*

PARASITIC ANTENNA—An antenna that is excited by radiation from other antennas rather than by electrical connection with them.

PARASITIC OSCILLATIONS—Oscillations which occur at other than the desired frequency in oscillators, or random oscillations in audio and radio frequency circuits. These oscillations are always undesirable.

PARASITIC REFLECTOR—A parasitic antenna so placed that the radiation from the driven antenna is reduced in one direction and reinforced in the opposite direction. See also, *Director, Reflector* (2).

PATTERN—(1) The geometrical figure used to show the directional qualities of the antenna assembly. (2) Position on selector switch of monitor scope.

PEAK—The maximum instantaneous value of a varying voltage, current, or power.

PEAKING CIRCUIT—A circuit used to sharpen a wave of any form, whereas a differentiating circuit is designed to sharpen a square wave.

PEDESTAL PULSE—A square wave pulse or gate upon which may be superimposed a video signal or sweep voltage.

PENCIL BEAM—An antenna beam in which energy is confined to a narrow, approximately conical portion of space.

PENCIL MIXER—A form of crystal mixer.

PERDIO—Performance data relative to radio ranges and reception.

PERSISTENCE—The measure of the length of time during which phosphorescent light is emitted from the screen of a cathode-ray tube. Long persistent screens are used on intensity-modulated indicators, as the PPI, while test oscilloscopes and deflection type radar indicators use short persistent screens. The persistence of the screen is indicated by the final number in the type designation of the tube. A 5CP1 is of short persistence, and a 7BP7 is of long persistence.

PERSUADER—Element of storage tube directing secondary emission to electron multiplier dynodes.

PHANTASTRON—A very stable triggered gate-producing circuit using a pentagrid tube.

PHANTOM SIGNALS—Signals appearing on the screen of a CRT Indicator the cause of which cannot readily be determined and which may be caused by circuit fault, interference, propagation, jamming, etc.

PHASE ANGLE—The time difference, expressed in electrical degrees, between the occurrence of the positive peaks of two sine waves of the same frequency.

PHASE DETECTOR—A circuit which detects both the magnitude and the sign of the phase angle between two sine-wave voltages or currents.

PHASE DISTORTION—Exists in an amplifier when the relative phases of the various frequency components in a complex input voltage are not preserved in the output voltage.

PHASE INVERTER—A stage of amplification giving two output signals, equal in amplitude but differing in phase by 180 degrees.

PHASE MODULATION—A form of FM in which only phase is varied while amplitude and frequency remain constant.

PHOSPHOR—A chemical compound which has the property of giving off light when bombarded by fast-moving electrons. Phosphors are used to coat the inner face of cathode-ray tube screens. See *Phosphorescence* and *Fluorescence.*

PHOSPHORESCENCE—The property of emitting light for some time after excitation by electronic bombardment.

PHOTOELECTRIC TUBE—Vacuum tube in which electron emission results from light energy striking light-sensitive cathode.

PHOTO-SENSITIVE—Capable of emitting electrons when illuminated by light rays.

PIGTAIL—A short flexible lead connected to a part or terminal.

PILLBOX ANTENNA—A narrow cylindrical parabola antenna reflector with plain parallel plates covering the ends.

PILL TRANSFORMER—An impedance matching device for coaxial transmission lines, consisting of a quarter wavelength of enlarged center conductor which can be adjusted longitudinally.

PIP—A short, sharply peaked wave of current or voltage. The echo indication on a type A scope.

PITCH—The motion of a ship in which the bow rises and falls as a result of oscillation about a transverse axis.

PITCH ANGLE—For any system of stabilization. The angle between the ship's deck and a horizontal plane, measured in a vertical plane including the fore and aft axis of the ship. This quantity is positive if the ship's bow is depressed.

PLAN POSITION INDICATOR—See *PPI.*

PLANE POLARIZED WAVE—In such a wave the electric intensity is everywhere parallel to some plane and the magnetic intensity is everywhere perpendicular to that plane.

PLATE PULSING—A method of modulating a transmitter in which the plate voltage is normally low until the application of a pulse of full plate voltage to produce oscillations.

PLUMBING—Refers to all ultra-high frequency r-f transmission line systems.

POLARITY SELECTOR—Control box for selection of polarity of trigger, signal, etc.

POINT—To control motion in elevation—as a gun or an antenna.

POLARIZED WAVE—A wave in which the electric lines are parallel. If the electric field is vertical, the waves are known as vertically polarized; if horizontal, horizontally polarized.

POLYPLEXER—See *T-R Box.*

POLY-ROD ANTENNA—An antenna made of a tapered rod of polystyrene. Usually excited by a wave guide.

POLYSTYRENE—A plastic insulating material most useful at ultra-high frequencies.

PORT—Left side of an aircraft or ship when facing the nose or bow.

POSITIVE FEEDBACK—See *Regeneration.*

POSITIVE-GRID MULTIVIBRATOR—A type of multivibrator which has one or more grids connected to the plate voltage supply usually through large resistance.

POTENTIAL—The difference in voltage existing between one point in a circuit and another point.

POTENTIOMETER—A resistor having a tap which can be continuously varied over the entire length of the resistor as a means of changing the resistance between two points in a circuit.

POWER—The time rate of transferring or transforming energy.

PPI (PLAN POSITION INDICATOR)—An indicator on which echoes appear as bright arcs. The sweep moves radially from the center of the tube face, and the sweep line rotates synchronously with the antenna. Thus, the radial distance at which the echo appears is an indication of range, and the angular distance measured clockwise from 12 o'clock is an indication of bearing.

PPI DRIVER—Unit containing necessary power supply, sweep, marker gate, and other circuits essential to the operation of a separate repeater PPI scope.

PPI REPEATER—Unit which repeats PPI indication at a location remote from the radar console.

PREAMPLIFIER—(1) The r-f amplifier stage or stages in a superheterodyne receiver which amplify the incoming modulated r-f signal before it is converted to the r-f signal by the mixer. The preamplifier is often located near the receiving antenna. (2) The two or three stages of the i-f amplifier that immediately follow the mixer in some microwave receivers, mounted in a unit near the antenna, and separate from the rest of the receiver.

PRECISION PPI—The model VF repeater PPI, which displays targets on both a 5-inch PPI scope and 5-inch B scope. Any area of the PPI pattern 30° in angular width and 4000 yards long in range can be displayed on the expanded B scope. A highly accurate ranging circuit is provided to measure ranges out to 40,000 yards.

PRECISION RANGE UNIT—Extremely accurate range unit for fire control radar.

PRECISION SWEEP—Delayed expanded sweep for high resolution and range accuracy. A type of *R scope.*

PREDICTER—A form of computer.

PRE-PLUMBED SYSTEM—Fixed, non-tunable wave guides or coaxial transmission lines.

PRESENTATION—The form which the radar echo signals are made to take on the CRT screen, which is dependent on the nature of the sweep circuit utilized. Examples: A-scope presentation, PPI scope presentation.

PRESENTATION SELECTOR—Selection of CRT indicator display.

PRESSURIZED—The filling of the r-f line with air at a pressure greater than atmospheric. Its purpose is two-fold: (1) to prevent breakdown of the components at high altitudes and (2) to protect against transmission losses caused by materials in the atmosphere, such as dirt and water.

PRE-T-R—Additional T-R Box to provide increased attenuation of transmitted pulse so as to prevent damage to crystal mixer.

PRE-TRIGGER—Trigger used to initiate sweep ahead of transmitted pulse.

PROBE—A projecting rod placed in the slotted section of the RF line, and used to pick up RF energy, in the determination of standing wave ratio (SWR).

PROJECTION PPI—Model VG repeater PPI. A unit in which the image of a 4-inch dark-trace cathode-ray tube is projected on a 24-inch horizontal plotting surface. The echoes appear as magenta-colored arcs on a white background. Also called a *Skiatron.*

PSEUDO-SYNCHRONIZER—Unit for supplying simulated data for testing decoder.

PULLING—See *Frequency Pulling.*

PULSATING CURRENT—A current which changes in value but not in direction.

PULSE—A momentary sharp change in a current or voltage, followed almost immediately thereafter by sharp return to normal.

PULSE AMPLIFIER—A circuit which amplifies the pulse waveform without materially altering its shape. Video amplifier.

PULSE ANALYZER—A special oscilloscope used with a search receiver for the purpose of measuring the pulse repetition rate and pulse width of intercepted radar signals.

PULSE DOPPLER (COHERENT)—A radar system for distinguishing between fixed and moving targets by detecting the frequency difference between echo and coherent c-w oscillator locked in phase with transmitted pulse. Video pulses from one repetition period are stored and mixed out of phase with pulses from the next period. Echo signals from fixed or slow-moving targets are cancelled, and only echoes from fast-moving targets remain in the receiver output to be displayed on the PPI.

PULSE DOPPLER (NON-COHERENT)—Uses doppler beats between the moving target and clutter at the same range to give MTI by aural indication of target in range gate.

PULSE DURATION—The elapsed time between the start and finish of a single pulse. See *Pulse Length.*

PULSE-FORMING LINE—A combination of circuit components used to produce a square pulse of controlled duration. See *Guillemin Line.*

PULSE INTERVAL—Time between corresponding points of successive pulses.

PULSE LENGTH—The duration of the pulse in microseconds at .85 of peak voltage value is the nominal length used in peak power calculations, while duration at ½ of peak voltage is maximum length used for receiver band with calculations.

PULSE MODULATION—Transmission of r-f energy in short pulses.

PULSE REPETITION RATE (PRR)—The number of pulses transmitted per second.

PULSE TIMER—Unit which automatically causes radar to emit short series of pulses at intermittent intervals.

PULSE TRANSFORMER—A special type of transformer designed to pass pulse currents and voltages as distinguished from the usual sine-wave type of transformer. Its major features are high-voltage insulation between windings and to ground, low capacitance between windings, and low reactance in both windings.

PULSED OSCILLATOR—An oscillator which is made to operate repetitively, usually at a low duty cycle (i.e., having the pulses short compared with the intervals between them).

PUSH-PULL AMPLIFIER—A system driving two tubes with equal voltages which are always of opposite polarity (180° out of phase).

PYRAMID WAVE—A triangular wave the sides of which are approximately equal in length.

Q FACTOR—A figure used to express the efficiency of coils and capacitors and resonant circuits. It expresses the ratio between the total energy in the circuit and the energy that is dissipated. A high-Q circuit is very selective of the frequencies that it will pass, and oscillations set up in such a circuit will persist for a relatively long time because the energy in the oscillations is dissipated slowly. The numerical value of Q is commonly found by dividing the inductive reactance or capacitive reactance by the resistance of the circuit.

QUARTER-WAVE SUPPORT—A method of insulating the inner from the outer conductor of a coaxial transmission line. A quarter-wave metallic stub is used in place of dielectric insulators.

QUARTER-WAVE TRANSFORMER—A quarter-wave section of line used to match the impedance of one circuit to another. It can be used as an interstage coupling device or in transmission lines. The input is placed across the open end and the output tapped off at the point, determined by test, which provides the proper impedance match. Also used as a voltage step-up or step-down transformer by tapping both the input and output signals at proper points along the line.

QUARTZ CRYSTAL—See *Crystal.*

QUENCH FREQUENCY—An a-c voltage applied to an electrode of a tube used as a super-regenerative detector. It alternately varies the sensitivity of the detector, thereby preventing any sustained oscillation. The quench frequency is usually low in comparison with the signal frequency to be received.

QUENCH OSCILLATOR—That circuit in a super-regenerative receiver which produces the quench frequency signal.

QUIESCENT STATE—The time during which a tube or other element of an electric circuit is not performing its active function in the circuit.

R INDICATOR—Expanded Type A Presentation. Also called *R scope* or *R scan.*

RACON—See *Radar Beacon.*

RADAR—Originally Radio Detection and Ranging. It has since been expanded to include all types of echo-ranging radio equipment.

RADAR BEACON—A receiver-transmitter combination which sends out a coded signal when triggered by the proper type of pulse. A vessel or aircraft can determine its range and bearing from the beacon by tuning the radar to the beacon frequency.

RADAR COUNTERMEASURES (RCM)—The means employed to obtain information about enemy forces from his use of radar, and to prevent him from obtaining any accurate or useful information about our forces through the use of his radar. Countermeasures methods are of four types: interception, jamming, deception and evasion. See *Radseven* and *Radeleven.*

RADAR DISTRIBUTION SWITCHBOARD (RDS) — Switching panel for connecting video, trigger, and bearing from any one of five systems to any or all of 20 repeaters. Also contains order lights, bearing cutouts, alarms, test equipment, etc.

RADAR INDICATOR—A unit of radar equipment which provides a visual indication of the reflected energy received, using a cathode-ray tube or tubes for such indication. The radar indicator comprises, besides the cathode-ray tube, the sweep and calibration circuit, and associated power supplies.

RADAR RECEIVER—An instrument which amplifies radio frequency signals, demodulates the r-f carrier, further amplifies the desired signal and delivers it to the indicator. It differs from the usual radio receiver in that it is more sensitive, has a lower noise level, and is designed to pass a pulse type of signal.

RADAR REPEATER ADAPTER—Unit which takes one video and trigger input and delivers several standard *PPI* video and trigger outputs suitable for driving *PPI Repeaters.*

RADAR SELECTOR SWITCH—A manual or motor-driven switch which transfers a *PPI Repeater* from one system to another, switching video, trigger and bearing data.

RADAR SIGNAL-NOISE RATIO—Ratio between echo height and average height of grass.

E Units	*Ratio*	*Description*
E-1	1 to 1	Barely Perceptible
E-2	2 to 1	Weak
E-3	4 to 1	Good
E-4	8 to 1	Strong
E-5	16 to 1	Very Strong or Saturating

RADAR TEST SCOPE—A combination synchroscope and oscilloscope provided with fast sweeps, which enables the examination of wave forms and voltages throughout the radar set.

RADAR TRANSMITTER—A unit of radar equipment in which the radio-frequency power for radar action is generated and keyed. Corresponds to radio transmitter in communications.

RADEX—An exercise designed to train radar operators to read through jamming and to acquire skill and confidence in the use of anti-jamming techniques and equipment. Sometimes loosely used to include the whole field of radar anti-jamming.

RADIATION—(1) The process wherein a transmitting antenna system converts the r-f output of the transmitter into radio waves which travel away from the station. (2) A control. On-Off-Momentary switch for operating the transmitter.

RADIATION PATTERN—See *Lobe* and *Pattern.*

RADIATION RESISTANCE—A fictitious resistance which may be considered to dissipate the energy radiated from an antenna.

RADIO BEACON—A radio transmitting station, usually in a fixed geographic location, which emits a distinctive or characteristic signal for enabling mobile stations to determine bearings or courses.

RADIO FREQUENCY—Any frequency in the spectrum of electromagnetic waves having a value below that of heat but above the highest audio frequency: abbreviated r-f.

RADIO-FREQUENCY AMPLIFIER—A vacuum tube and associated circuit designed to provide amplification at radio frequencies.

RADIO WAVE—A combination of transverse electric and magnetic fields, each building up and collapsing at a radio frequency and capable of traveling through space at the speed of light. See *Electromagnetic Field.*

RAILING—A pattern on type *A* Indicator caused by pulse interference or pulse jamming.

RAISE—Refers to voltage, gain, frequency, etc.

RANDOM PULSING—Continuous varying *PRR* accomplished by noise modulation or continuous frequency change.

RANDOMIZED JITTER—Jitter by means of noise modulation.

RADOME—A general name for radar turrets which enclose antenna assemblies.

RANGE—The number of miles between any two points, usually measured in yards or nautical miles. A nautical mile is 6080.27 feet, but for convenience in radar and navigation, the nautical mile is said to be 6000 feet, or 2000 yards long. The statute mile is 5280 feet long.

RANGE BUZZER—Circuit to remote indicator for calling attention to range transmission.

RANGE CALIBRATE—Calibration of range counter or dial against electronic markers.

RANGE CODING—A method of coding a beacon response in which the reply consists of a group of pulses extending out in range from the range of the beacon. The coding lies in the arrangement of these pulses as they show on the scope.

RANGE-HEIGHT INDICATOR—See *RHI*.

RANGE GATE—A gate voltage used to select echoes from a very short range interval.

RANGE MARKS—Pips or complete traces superimposed on the video signal and supplied to a cathode ray tube at specific intervals. They are used for calibration purposes.

RANGE MARK OFFSET—Displacement of range mark on a type "B" indicator.

RANGE RATE—Control of rate of range change.

RANGE RING—Accurate adjustable ranging mark on *PPI*. Corresponds to a range step on type M indicator.

RANGE SELECTOR—Control for selection of range scale.

RANGE STEP—Vertical displacement on "M" Indicator sweep to measure range.

RANGE UNIT—A radar system component used for control and indication (usually counters) of range measurement.

RANGE ZERO—Alignment of start of sweep trace with zero range.

RASD—Radar antenna stabilization director.

RATE—Used with range, bearing, elevation, etc.

RC COUPLING—Coupling between two circuits by means of a resistance-capacitance network.

RCM—Radar countermeasures.

RC NETWORK—A circuit containing resistances and capacitances.

REACTANCE—Impedance offered to the flow of alternating current by the inductance or capacitance of a radio circuit or part thereof. Reactance is measured in ohms, and depends upon the frequency of the alternating current as well as upon the actual magnitude of the inductance or capacitance. A capacitor has capacitive reactance while a coil has inductive reactance. Capacitive reactance causes current to lead the voltage and inductive reactance causes current to lag behind the voltage in phase.

REACTANCE TUBE—A vacuum tube used to change the reactance of a circuit.

READ—Target Indication indicator light.

READY—Indication of completion of standby condition.

RECEIVER—Unit for converting r-f energy into video or audio frequencies.

RECEIVER GAIN—Control of output of receiver. See *Gain*.

RECEIVER GATING—Applying operating voltages to one or more i-f stages during only the interval when reception is desired.

RECEIVER TUNE—A control for adjustment of receiver L.O. frequency.

RECOGNITION—The process of determining the friendly or enemy character of others. See *Identification*.

RECOVERY TIME (OF RECEIVER)—The time required for the receiver to recover to within approximately 3 db of full sensitivity, after the main transmitted pulse stops.

RECOVERY TIME (OF TR)—Time required, after an r-f pulse has fired the gap in the TR cavity, for the ions to recombine. Time after the end of the gap discharge when a received signal is 3 db down from one received a long time after the ions have recombined.

RECTIFICATION—The conversion of alternating current into unidirectional current by means of a tube or crystal.

RECTIFIER—A device which passes current more easily in one direction than in the other. Common types of rectifiers include two-element vacuum tubes, gaseous tubes, crystals, and copper-oxide devices. Used in Rectifier Power Units, High Voltage Rectifiers, Regulated Rectifiers, etc.

REFLECTED—Refers to a wave traveling in a direction away from the load.

REFLECTOMETER—Unit for measuring standing waves of voltage and power.

REFLECTOR—(1) A device to redirect radiation in a desired direction or directions. (2) A parasitic element which reinforces radiation on a line pointing from it to the antenna. (3) An anode in a reflex klystron tube which reflects the electrons back toward the grid. Also called a repeller.

REFERENCE VOLTAGE—In a synchro servo system, the a-c voltage used to determine the in-phase or 180° out-of-phase condition in order to provide directional sense.

REFLEX KLYSTRON—A klystron in which a single cavity is used both as buncher and catcher. The bunched electrons pass through the cavity and are then reversed in direction by means of a negatively charged repeller electrode.

REFRACTION—The bending of light or radio waves which takes place when the energy passes from one medium into another. The variation of the transmission properties of air caused by temperature inversion and cold-wave fronts may cause a certain amount of refraction to radio waves. However, for convenience the radiation from radar equipment is often assumed to travel in straight lines.

REGULATED RECTIFIER—Unit for supplying d-c power at constant voltage in spite of load or line supply voltage variations.

REGENERATION—A method of increasing the amplification of an amplifier by feeding a portion of the amplifier output back to the amplifier input in such a way that reinforcement of the input signal is obtained.

REGENERATIVE RECEIVER—A radio receiver which employs controlled regeneration to increase the amplification provided by a vacuum tube stage.

REJ—*AJ* controls for tuning the band elimination, or rejection, filters through the i-f band of the receiver.

RELATIVE—The angle between the vertical plane through the fore and aft axis of own ship and the vertical plane through the line of sight, measured in a horizontal plane clockwise from the bow. A bearing measured with respect to own ship's heading.

RELAXATION OSCILLATOR—An oscillator in which a capacitor is charged slowly through a resistor and then discharged rapidly through a tube.

RELAY—An electromagnetic device which permits control of the current in one circuit by a much smaller current flowing in another circuit. This is accomplished by causing an electromagnet to open or close a switch.

REMOTE CAGING CONTROL (OF FLUXGATE COMPASS)—A device (manual or electrical) for caging the gyro of the gyro fluxgate compass system, when it is not in use. The gyro is caged to protect the gyro assembly from damage when the system is not operating. The caging mechanism is operated before the power is shut off.

REMOTE PPI—See *PPI Repeater.*

REMOTE-LOCAL—Shift of control from main control to general control at Indicator Console.

REPELLER—Element of Reflex klystron oscillator. See *Reflector* (*3*).

RESET—Overload relay reset.

RESISTANCE COUPLING—A type of coupling in which a resistor and capacitor provide a path for signal energy between two circuits. See *RC Coupling.*

REPETITION RATE (PRR)—The number of pulses sent out by the transmitter per second.

RESOLUTION—1. *Range.* The minimum range difference between two targets on the same bearing that will allow the operator to obtain data on either target. 2. *Bearing.* The minimum angular separation between two targets at the same range that will allow the operator to obtain data on either target. 3. *Elevation.* The minimum angular separation between two targets at the same range and bearing that will allow the operator to obtain data on either target.

RESOLVER—An electro-mechanical unit, similar to a synchro, used to resolve incoming voltages into their sine and cosine components as referred to angle of shaft rotation. Resolvers may be supplied with two stator and two rotor windings for resolution of the sine and cosine components of the vector sum of two quadrature inputs.

RESONANCE—In a circuit containing both inductance and capacitance, a condition in which the inductive reactance is equal to the capacitive reactance at a particular frequency. In parallel resonance, the impedance presented appears as a high value of pure resistance. In series resonance, the impedance presented appears as a low value of pure resistance. When two bodies, or two currents, or two voltages which are coupled oscillate at the same frequency they are said to be in resonance.

RESONANCE INDICATOR—Meter indicating condition of resonance. Used with Reflectometer, Wave meter, Echo Box, etc.

RESONANT CAVITY—See *Cavity Resonator.*

RESONANT CHARGING CHOKE—Modulator inductor which, with the effective capacitance of a pulse-forming network, is used to set up an oscillation of a given charging frequency in order to charge the line to a high voltage.

RESONANT FREQUENCY—The frequency at which resonance occurs in an LC tuned circuit. That frequency of vibration which causes maximum amplification of applied vibration.

RESONATOR—A resonant cavity, the frequency of oscillation of which is determined primarily by the physical dimensions.

RESPONSOR—A radio receiver, associated with the radar equipment, which receives the reply returned from the *Transpondor* and produces an output suitable for feeding to a display system. The *Responsor* usually is combined into a single unit with the *Interrogator.*

RETRACE—The return of a trace on the screen of a *CRT* to its starting point. Usually blanked out. Sometimes called *Flyback* or *Backtrace.*

RF—Radio Frequency.

RF CHOKE—A choke of low inductance, used to prevent radio-frequency currents from passing from one circuit to another.

RF-IF CONVERTER—See *Preamplifier.*

RF LINE—The system of metallic tubes (wave guides and/or coaxial lines) which conducts r-f energy from one point to another. Also referred to as "plumbing."

RF PLUMBING—Radio-frequency transmission lines and associated equipment.

RHI—Range-Height Indicator. Intensity modulated radar indicator which displays elevation on vertical axis and range on horizontal axis.

RHUMBATRON—A re-entrant hollow-cavity, velocity modulated oscillator.

RING OSCILLATOR—A type of oscillator used in some radars in which any even number of tubes are arranged in a ring. Between each pair of adjacent tubes is a tuned quarter-wave line functioning as a balanced tank circuit. The open ends of each line are connected either to two grids or two plates, alternating around the ring. Coupling between plate and grid circuits is chiefly through the internal capacitance of the vacuum tubes. The balanced nature of each tank circuit puts equal r-f voltage of opposite polarity on adjacent tubes.

RIBBON MARKER—Intensified annular segment of precision *PPI* (model VF), indicating *B*-scope area.

RINGING OSCILLATOR—An oscillator circuit containing an LC resonant combination in the cathode circuit. Usually used to provide range marks.

RINGING TIME—See *Echo Box.*

ROLL—The motion of a ship in which it inclines first to one side and then to the other; an oscillation about the fore and aft axis of the ship. Owing to the structure of the ship there is no roll without pitch, but it is theoretically possible to have pitch without roll.

ROLL ANGLE—(For any system of stabilization.) The angle between the ship's deck and a horizontal plane, measured in a plane perpendicular to the fore and aft axis of the ship. This quantity is positive if the starboard side of the ship is raised.

ROPE—Metal foil about 400 feet long, untuned and effective for passive jamming from 50 to about 350 mc.

ROTARY SPARK GAP—A device in which several electrodes mounted on a wheel are rotated past a fixed electrode, producing periodic spark discharges. Used in radar modulators.

ROTATING JOINT—A device for permitting one section of a transmission line to rotate continuously with respect to the other and still maintain r-f continuity.

ROTOFLECTOR—A rotating reflector, elliptically shaped, used to reflect at right angles a vertically directed radar beam so that it illuminates in a horizontal direction.

ROTOR—The rotating member of a machine.

ROUND TRIP ECHOES—Multiple reflection echoes produced when the radar pulse is reflected from a target strongly enough that the echo is reflected back to the target where it produces a second echo. As many as four round trips have been observed, producing on the indicator a series of pips on the same bearing which are at the true range, twice the true range, etc. These echoes decrease markedly in size on each succeeding round trip because of the great attenuation involved in the several reflections.

RPD—Radar Planning Device. A system in which a topographical relief model and a narrow beam of light are used to simulate PPI presentations by photographing the light and shadow areas on the model.

RPPI—Repeater Plan Position Indicator. See *PPI Repeater.*

RR EQUIPMENT—Radio recognition equipment. See *IFF.*

RT BOX—A standard TR tube contained in a cavity with no output circuit. The RT box is placed on the line between the TR and the magnetron, and $\lambda/4$ away from the TR box. It is part of the duplexing system and prevents radar echoes from feeding into the magnetron.

SAND LOAD—An attenuator used as a terminating section on a transmission line to dissipate power. The space between inner and outer conductors is filled with a sand and carbon mixture which acts as the dissipative element.

SATURATE—Overloading a vacuum tube to the limit of its emission and amplifying capabilities.

SATURATED SIGNAL—The maximum possible signal that may be observable on a CRT.

SAW-TOOTH WAVE—A voltage or current wave which increases linearly to a maximum and then falls off to a minimum in a relatively short period of time. The retrace or backtime is usually less than 10% of the total cycle time.

SAXOPHONE—A vertex-fed linear array antenna giving a cosecant-squared radiation pattern.

SCALE-OF-TWO CIRCUIT—A system for dividing by two the number of input pulses. A frequency divider.

SCAN CONVERTER—Unit for converting electronic scan data to synchro bearing data.

SCANNER—A type of antenna in which a paraboloidal reflector is made to oscillate back and forth about a center position. The oscillation may be in a horizontal or a vertical plane or in a combination of both.

SCANNING—1. The process of directing the r-f beam successively over all points in a given region of space. 2. The process of deflecting the beam of a cathode-ray tube to all parts of the screen as a means of forming a pattern.

SCATTER-BAND—The band of frequencies within which the principal operating frequency of any given transmitter tube type is permitted to vary.

SCATTERING CROSS SECTION OF A TARGET—The ratio of the power reflected from, to the power incident on a given target. It depends on size, configuration, aspect, and composition of the target, and the wavelength and polarization of the r-f energy.

SCHWARZCHILD ANTENNA—A rapid-scanning antenna.

SCI—Ship-controlled interception.

SCREEN—See *Fluorescent Screen* and *Long Persistence Screen.*

SCREEN GRID—An electrode placed between the control grid and plate of a vacuum tube for the purpose of increasing the gain of the tube and of reducing the capacitance between these two electrodes.

SEA RETURN—The indication on a radar indicator caused by radio waves being reflected by the surface of the sea.

SEARCH—Refers to a radar system whose primary function is detection with moderately accurate range, bearing, elevation, and target composition data. *Dual Search*—Two separate search systems combined on one mount. *General Search*—Combined air and surface search. *Height-Finding Search*—Long-range early warning and elevation of aircraft in addition to long range surface search. *High Resolution Search*—System with high range and azimuth resolution for navigation, station keeping and standby fire control. *Long-Range Search*—High-power system for detection of planes at extreme range. *Panoramic Search*—Complete hemispheric search (short range) with range, bearing, and elevation data. *Range-Only Search*—Omnidirectional or wide-angle search primarily for warning or range data. Bearing obtained by optical means. *Surface Search*—Detection of surface targets and low-flying planes at maximum range. *Zenith Search*—Detection of aircraft in region 20° to 90° elevation and 360° azimuth.

SEARCH RECEIVER—A special calibrated receiver which can be tuned over a wide frequency range in order to detect and measure r-f signals transmitted by the enemy.

SEARCHING GATE—A gate pulse which is made to search back and forth over a certain range.

SEARCHLIGHT CONTROL RADAR (SLC)—Equipment for directing searchlights onto aircraft.

SEARCHLIGHTING—Directing the radar beam continuously at any given object or target, instead of illuminating it once during each scan period.

SEASONING—Overcoming a temporary unsteadiness of the magnetron which may appear when it is first installed.

SECONDARY EMISSION—Emission of electrons from a tube element other than the cathode when the element is bombarded by high-velocity electrons.

SECONDARY INDICATOR (OF FLUX GATE COMPASS)—A repeater unit which duplicates at a remote station the indications of the master indicator of the gyro flux gate compass system.

SECOND DETECTOR—See *Detector.*

SECOND TRIP ECHOES—Echoes returned from targets so distant that the time required for the radar pulse to go out to the target and return to the set is longer than the interval between pulses. These echoes show up at false ranges, and the apparent range can be changed by varying the pulse repetition rate.

SECTOR SCAN—A type of scanning in which the antenna pattern is made to scan back and forth through a sector of a circle.

SELECTIVITY—The degree to which a radio receiver is capable of receiving signals of one frequency or band of frequencies while at the same time discriminating against signals of all other frequencies.

SELECTOR SWITCH—A switch arranged so that a conductor may be connected to any one of several other conductors.

SELF-BIAS—A means of biasing the grid without applying a negative voltage derived from a special power supply, as by using a cathode resistor or a grid leak.

SELF PULSING—A special type of grid pulsing which automatically stops and starts the oscillations at the pulsing rate by a special circuit.

SELSYN—A trade name. See *Synchro.*

SENSITIVITY—A measure of the ability of a receiver to amplify a signal. It is measured by the input signal required to produce a certain fixed output signal. The lower the input signal for a given output, the higher the sensitivity.

SENSITIVITY-TIME CONTROL (STC)—A circuit which reduces receiver sensitivity for the first few thousand yards of each sweep, and then gradually restores it to normal. Helpful in reducing the effect of sea return and side lobes.

SEPARATION—Horizontal spacing of pattern, lobe, signal, trace, etc.

SEPARATOR—Circuit at receiving end of link which separates video, trigger, and scan data.

SERVICE OUTLET—Outlet for providing servicing power conveniently on the front of the equipment.

SERVICE PHONE—Servicing phone jack.

SERVICE SWITCH—Line switch in service power.

SERVICING BLOCK—A block diagram containing wave forms, terminals, signal paths, tubes, and other data useful for servicing.

SERVO AMPLIFIER UNIT—A unit of a servo system in which information from a synchro is amplified in order to control the speed and direction of the servo motor output.

SERVO SYSTEM—A complete electromechanical system for amplifying and transmitting accurate mechanical position. Servo motor, Servo generator, Servo amplifier, etc.

SHAPING—Adjustment of *PPI* pattern set up by rotating magnetic field.

SHARPENER AMPLIFIER—A peaking circuit plus an amplifier.

SHEPHERD TUBE—The Shepherd-Pierce tube, type 723A. A microwave local oscillator, all-metal velocity modulated tube.

SHF—Super-high frequencies (3,000 to 30,000 megacycles).

SHIELD—A grounded metal can or housing placed around a radio part to prevent its electric and magnetic fields from affecting nearby parts, or to prevent other fields from affecting it.

SHIP HEADING MARKER (SHM)—An electronic radial sweep line on PPI indicating heading of own ship.

SHIP'S HEAD—See *Heading*.

SHOCK MOUNTING—Placing a component on rubber supports to insulate it from jarring or shock which might disturb its operating characteristics or damage the equipment.

SHORT CIRCUIT—An abnormal connection of relatively low resistance, whether made accidentally or intentionally, between two points of different potential in a circuit.

SHORT GATE GAIN—Video gain on short-range gate.

SHOT EFFECT—Noise caused by the random impact of electrons in a vacuum tube. This causes slight instantaneous variations in the output current of a tube.

SHUNT—Any parallel-connected part, or the act of placing one part in parallel with another.

SICKLES CALIBRATOR—A range calibrator using a circular-sweep tube, and which is stabilized by a crystal oscillator.

SIDEBANDS—When the amplitude or frequency of a high-frequency wave is varied at a comparatively low-frequency rate, the high-frequency wave is said to be modulated. The resultant wave has a component wave of the high-frequency plus other frequencies that depend on the modulation frequency or rate. These are the sidebands.

SIDE LOBE—A portion of the beam from a radar antenna, other than the main lobe, and usually much smaller.

SIGNAL—A radio wave or alternating current which carries intelligence of any form. More generally, any alternating current having other than a power-line frequency.

SIGNAL GENERATOR—A test instrument used to produce a modulated or unmodulated r-f carrier signal at a known frequency and in some cases at a known voltage. It is used as a signal source during alignment of a radio receiver and in locating the defective part in an improperly operating receiver.

SIGNAL-TO-NOISE RATIO (S/N)—The ratio of the amplitude of a desired signal at any point to the amplitude of noise signals at that same point. The higher the signal-to-noise ratio, the less noise, or grass, there is to interfere with the observation of target indications.

SILICA GEL—A chemical having moisture absorption properties, used in connection with the dehydrator in removing moisture from the air supplied to the transmission line in radar equipment.

SILVERSTAT REGULATOR—A multi-tapped resistor, the taps of which are connected to single-leaf silver contacts. Variation of voltage causes a solenoid to open or close these contacts, shorting out more or less of the resistance in the excitor circuit as a means of regulating the output voltage to the desired value.

SINGLE STUB TUNER—A short section of transmission line terminated by a movable short-circuiting plunger. Used as an impedance matching device.

SITING—The proper location of a radar antenna in order to obtain optimum performance.

SIZE—Control of size of *PPI* indication by varying *PPI* sweep length.

SKIATRON—A type of PPI in which the image of a dark-trace tube is projected on a screen larger than the tube face.

SKY WAVES—Radio waves which travel up into the sky from the transmitting antenna and are bent back to earth by the Ionosphere.

SLANT RANGE—The distance in a straight line from a radar set to a target.

SLEWING MOTOR—Motor drive of antenna control synchro or handwheel.

SLICER—A circuit which effectively amplifies a portion of the incoming pulses lying between two closely spaced amplitude levels.

SLIP RING—Device for making electrical connections between stationary and rotating contacts.

SLOTTED SECTION—A slot in a transmission line along which a probe is moved to measure *SWR*.

S/N—Signal-to-noise ratio.

SNOW—The low, fairly regular indications on the *PPI* caused by noise.

SOFT TUBE—(1) A high-vacuum tube which has become defective because of the entry of a small amount of gas. (2) An electronic tube into which a small amount of gas has purposely been put in order to obtain desired characteristics. A gaseous tube.

SOLID DIELECTRIC CABLE—Made by extruding a flexible dielectric over the inner conductor, with braided copper wire to form the outer conductor, which may be tinned or plated. For microwave work, most cables are nominally 50 ohms. For IF and video, 70-ohm cable is more generally used.

SONAR—Underwater sound navigation and ranging equipment.

SPAGHETTI—Heavily varnished cloth tubing sometimes used to provide additional insulation for radio circuit wiring.

SPARE—Designation of spare fuse, tube, etc.

SPARK GAP—An arrangement of two electrodes between which a disruptive discharge of electricity may take place, such that the insulation is self-restoring after the passage of the discharge.

SPARK GAP MODULATOR—A modulator in which the high current switch takes the form of a spark gap. The spark gap may be either of the triggered or the rotary type.

SPARK PULSE MODULATOR—A modulator which generates pulses at high power level directly from a pulse-forming line. The spark may occur in air, or in a gas-filled tube.

SPECTRUM ANALYZER—A test instrument used to show the distribution of the energy contained in the frequencies emitted by pulsed magnetrons to measure the Q of resonant cavities or lines and to measure the cold impedance of a magnetron.

SPINNER—Name applied to the rotating antenna assembly on certain types of microwave radar sets.

SPIRAL SCANNING—A point on the r-f beam traces out a spiral. The motion is obtained by rotating the paraboloid rapidly about a horizontal axis, while tilting it more slowly about an axis at right angles to the first.

SQUARE WAVE—Any periodic wave rectangular in shape. Specifically, a rectangular waveform in which the positive and negative portions are of equal amplitude and duration.

SQUARE-WAVE AMPLIFIER—A resistance-coupled or RC amplifier, the circuit constants of which are such as to amplify a square wave with the minimum amount of distortion. In effect, a wide-band video amplifier.

SQUEEZABLE WAVEGUIDE—A waveguide used in rapid scanning, the dimensions of which can be altered periodically.

SQUEGGING OSCILLATOR—An oscillator usually operating at radio frequency, which oscillates briefly and then cuts itself off due to grid current. This action is repeated periodically. A self-pulsing oscillator.

SQUITTER—The irregular transmission of pulses that results from self-triggering of an IFF transpondor when the superregenerative receiver becomes so sensitive that it is operated by noise pulses instead of by interrogating pulses received in the normal manner.

SSI—Sector Scan Indicator.

STABILIZATION—A system for maintaining a radar beam in a desired direction in space despite the roll and pitch of the ship or aircraft. 1. *One-axis stabilization*—Same as Line-of-sight stabilization. 2. *Two-axis stabilization*—This is the same as line-of-sight stabilization except that provision is made for adding the deck-tilt correction to the train order. By this means the spinner is kept pointed at the target irrespective of the roll and pitch of the vessel or aircraft as long as the true bearing of the target does not change. Rotation occurs about two axes; namely, the level axis and the train axis. 3. *Three-axis stabilization*—This is the same as two-axis stabilization except that provision is made for rotation of the antenna about a true horizontal cross-level axis. More precisely the level axis and the line-of-sight are both maintained in a horizontal plane. As in two-axis stabilization, provision is made for adding the deck-tilt correction. Rotation occurs about three axes; namely, the level axis, the cross-level axis, and the deck-train axis. 4. *Four-axis Stabilization*—A stable-base system in which elevation stabilization is added. 5. *Line-of-sight Stabilization*—A method of compensating for roll and pitch of the vessel or aircraft by changing the elevation of the spinner in order to keep the radar beam pointed at the horizon. 6. *Stable-base Stabilization*—A method of maintaining the spinner base in a true horizontal plane by compensating for roll and pitch directly. The deck-tilt error does not occur when this method is used. In a stable-base system, rotation occurs about three axes; namely, the roll axis, the pitch axis, and the train axis. If it is desired to raise the radar beam above the horizontal, a fourth axis called the elevation axis must be added above the spinner base. 7. *Tilt Stabilization*—Stabilization by use of a gyroscope of the tilt angle of a spinner. Also called "line-of-sight" stabilization.

STABLE ELEMENT—A gyroscopic instrument which maintains a true vertical, and develops angles of deviation of the ship's deck from the true horizontal. The unit may be rotated in train, and has outputs of level and cross-level which may be used as input data to computers used in stabilization systems, or the outputs may be fed to the antenna directly.

STABLE PLATFORM SYSTEM—See *Four-axis Stabilization.*

STABLE VERTICAL—A gyroscopic instrument which is similar to the stable element except that it is not rotated in train and has outputs of roll and pitch only.

STACKED DIPOLE ANTENNA—Generic term applied to a number of antenna designs in which antenna directivity is increased by providing a number of identical dipole elements, excited either directly or parasitically. The resultant radiation pattern will depend on the number of dipole elements used, the spacing and-phase difference between the elements, and the relative magnitudes of the currents.

STAGGER TUNING—Method of aligning the i-f stages of a superheterodyne receiver in order to produce wide bandwidth. This is accomplished by peaking alternate i-f transformers at slightly different frequencies. Compare *In-line Tuning.*

STALO—An extremely stable c-w oscillator used as a local oscillator in the superheterodyne radar receiver in an MTI system. See *Coho.*

STANDBY—Condition of equipment which will permit complete stable operation within a short period of time.

STANDARD ATMOSPHERE—A condition of the atmosphere in which the temperature and the moisture content of the air decrease uniformly with height. In the standard atmosphere, the air temperature decreases with increasing altitude from 15° Centigrade at sea level at the rate of 6.5°C. per kilometer. Although this condition is postulated as "standard," it is not necessarily *normal* at any particular location. The atmosphere is likely to be of standard composition when strong, gusty winds are blowing because the turbulence created prevents both stratification of the air and establishment of non-standard temperature and humidity gradients.

STAND-OFF INSULATOR—An insulator used to support a wire, or other radio component, at a desired distance away from the structure on which the insulator is mounted.

STANDING WAVE—A distribution of current and voltage on a transmission line formed by two sets of waves traveling in opposite directions, and characterized by the presence of a number of points of successive maxima and minima in the distribution curves. Since standing waves indicate that power is being lost in transmission, efforts are made to keep standing waves to a minimum.

STANDING WAVE INDICATOR—An instrument containing a detecting device (bolometer, thermocouple or crystal) which enables one to determine the ratio of the maximum voltage to the minimum voltage of the combined incident and reflected waves. The deflection or current reading is proportional to the time average of the square of the voltage at any given point. Other SW detectors may read voltage directly.

STANDING-WAVE RATIO (SWR)—The ratio of the current (or voltage) at a loop or maximum to the value at a node or minimum. It is determined by the terminal and by the characteristic impedances.

STARBOARD—The right side of an aircraft or ship when the observer is facing its nose or bow.

START-STOP MULTIVIBRATOR—A biased rectangular wave generator which operates for one cycle when a synchronizing trigger signal is applied.

STATOR—The portion of an electrical machine which contains the stationary parts of the magnetic circuit with their associated windings.

STC—Sensitivity-Time Control.

STEP—Range mark offset on type M presentation.

STEP-BY-STEP—A system used for data transmission on older ships and on ships that have only d-c power available. The system consists of special d-c motors that are driven by a rotary switch which is controlled by the shaft whose position it is desired to duplicate at a remote location.

STIFFNESS FACTOR—Static accuracy—angular lag between input and output of a servo system.

STORAGE TUBE—A cathode-ray tube of special design in which signals can be stored or retained for a short time, after which the signals may be recovered without appreciable loss of identity.

STOW—Locking of antenna to prevent rotation while servicing.

STRAY CAPACITANCE—Capacitance existing between adjacent conductors or wiring. Coupling effects cause it to be detrimental at high frequencies. See *Distributed Capacitance.*

STROBE—An intensified spot in the sweep of a deflection type indicator, used as a reference mark for ranging or expanding the presentation.

STRUT—A tuning strut is a thermally controlled tuning member of the Nehr L.O. which changes the cavity dimension.

STRUT TIME CONSTANT—Time required for tuning to reach 64% $(1-\epsilon^{-1})$ of its final value after the application of unit step-function voltage to the tuning strut.

STUB—Device for matching, loading, or tuning in r-f system. See *Matching Stub.*

STUB ANGLE—A right-angle elbow for the coaxial r-f transmission line which has the inner conductor supported by a quarter-wave stub.

STUB-SUPPORTED LINE—A type of coaxial line in which the inner conductor is positioned coaxially by short-circuited quarter-wave stubs.

SUPERHETERODYNE RECEIVER—A type of radio receiver in which the incoming modulated r-f signals are amplified in a preamplifier (in some cases; but not necessarily in all receivers of this type), then fed into the mixer for conversion into a fixed, lower carrier frequency called the intermediate frequency of the receiver. The modulated i-f signals undergo very high amplification in the i-f amplifier stages and are then fed into the detector for demodulation. The resulting audio or video signals are usually further amplified before use.

SUPER-REFRACTION—See *Trapping.*

SUPER-REGENERATIVE RECEIVER—A type of regenerative receiver in which weak periodic oscillations are caused by the use of a quench frequency signal. This quench signal is fed to the receiving tube where it constantly varies the gain of the tube by varying an electrode voltage.

SUPPRESSOR PULSE—A pulse used to disable an IFF or beacon transpondor during intervals when interference would be encountered. See *Killer Circuit.*

SUPPRESSION—Suppression of noise, etc.

SURGE—A transient variation in the current and/or potential at a point in the circuit.

SWEEP—The steady bright line produced on the screen of a cathode-ray tube by the repeated deflection of the electron beam across the screen. The time base on which the range of an echo is measured in a radar indicator. Main, expanded, precision, etc.

SWEEP AMPLIFIER—A vacuum tube stage designed to increase the amplitude of the sweep voltage.

SWEEP CIRCUIT—A circuit which produces at regular intervals an approximately linear, circular, or other form of movement of the beam of the cathode-ray tube.

SWEEP DISPLACEMENT—Vertical displacement of sweep when used with *IFF.*

SWEEP GENERATOR—A sweep circuit.

SWEEP LENGTH—A control for adjusting the magnitude of sweep voltage.

SWEEP VOLTAGE—A voltage having a wave form suitable for deflecting an electron beam in a *CRT* back and forth across the fluorescent screen.

SWR—Standing wave ratio.

SYNCHRO—A type of wound-rotor a-c motor used for repeating angular motion both as to speed and total angle. The trade name *"Selsyn"* is often used synonymously with synchro, and is an abbreviation of the term "self-synchronous," and indicates the normal use of the equipment. See OP 1303, *U. S. Navy Synchros.*

SYNCHRO CONTROL TRANSFORMER—A synchro in which the electrical output of the rotor is dependent on both the shaft position and the electrical input to the stator.

SYNCHRO DIFFERENTIAL GENERATOR—The synchro unit which receives at its primary terminals an order from a synchro generator, modifies this order mechanically by any desired amount by the angular position of the rotor, and transmits the modified order from its secondary terminals to other synchro units.

SYNCHRO DIFFERENTIAL MOTOR—A motor which is electrically similar to the synchro differential generator except that a damping device is added to prevent oscillations. Both its rotor and stator are connected to synchro generators, and its function is to indicate the sum or difference between the two signals transmitted by the generators.

SYNCHRO GENERATOR—A synchro which has an electrical output proportional to the angular position of its rotor.

SYNCHRO MOTOR—A synchro in which the rotor shaft position is dependent on the electrical input.

SYNCHRONISM—The relationship between two or more periodic quantities of the same frequency when the phase difference between them is zero.

SYNCHRONIZER—That component of a radar set which generates the timing voltage for the complete set. See *Timer.*

SYNCHROSCOPE—An oscilloscope on which recurrent pulses or waveforms may be observed, which incorporates a sweep generator that produces one sweep for each pulse. The sweep usually is very fast in order to permit display of short pulses.

TAIL—A small pulse, following the main pulse and in the same direction; or the slow decay, following main body of pulse.

TAIL CLIPPING—Any method of sharpening the trailing edge of a pulse.

TARGET—Any distant object which will reflect a sufficient amount of signal to be evident at the searching set.

TARGET ALIGNMENT—Alignment of spot indication in center of scope when beam is directly on target (G Indication).

TELL TALE—Warning indicator which shows loss of synchronism between PPI rotation and antenna rotation.

TEMPERATURE ALARM—Warning indicator light or buzzer which indicates overheating.

TERMINAL—A point to which electrical connections are made.

TEST AMPLIFIER UNIT—Used to amplify output of echo box, bolometer, or other test equipment.

TEST—Referring to points of wave-form or voltage test.

TEST EQUIPMENT—An assortment of instruments provided with a radar set to enable the maintenance man to determine accurately whether the set is performing properly in its various functions.

TEST LEAD—A flexible insulated lead used chiefly for connecting meters and test instruments to a circuit under test at a test point.

TEST PROD—A sharp metal point provided with an insulated handle and means for electrically connecting the point to a test lead. It is used for making a touch connection to a circuit terminal.

TETRODE—An electronic vacuum tube in which four elements—cathode, control grid, screen grid, and plate—are used.

THERMAL AGITATION—Term applied to noise caused by random motion of free electrons in a conductor, which produces minute voltages across the terminals.

THERMAL TIME DELAY SWITCH—An overcurrent protective device which contains a heater element, and thermal delay.

THERMIONIC EMISSION—The evaporation of electrons from the body of a solid at high temperatures.

THERMISTOR—A sensitive resistor, used in the thermistor bridge, whose resistance varies significantly with temperature.

THREE AXIS STABILIZATION—See *Stabilization.*

THIRTY-SIX SPEED—A synchro system in which the rotor of the synchro generator turns 36 revolutions for every revolution of the shaft whose position is to be reproduced remotely. The 36-speed system is used to provide finer position control than is possible with a 1-speed system alone.

THYRATRON—Trade name for gaseous triode tube. The time at which current through the tube starts to flow is determined by the grid voltage. The amplitude of current flow is independent of the grid voltage once the tube begins to conduct.

THYRITE—A material that has high resistance when low voltage is impressed on it and low resistance when the voltage is high. Used in connection with the magnetron to prevent backswing.

TICKET TUBE—Material used as a waveguide for low or medium power microwave radar equipments. The material is a hollow brass pipe, rectangular in cross-section, with inside dimensions of approximately $\frac{3}{8}$" by $2\frac{3}{4}$".

TILT—The angle which the reflector makes with the horizontal.

TILT STABILIZATION—See *Stabilization.*

TIME BASE—The voltage generated by the sweep circuit or circuits in the radar indicator. The waveshape of the voltage generated is such as to cause to be described on the screen of the cathode-ray tube a trace which is either linear with respect to time, or, if non-linear, is still at a known timing rate.

TIMER—In radar, a generic term for an assembly of electric circuits and associated equipment which provides the following: (1) trigger pulses, (2) sweep circuits, (3) intensifier pulses, (4) gate voltages, (5) blanking voltages, and (6) power supplies. An important feature of a timer is that the various output events are synchronized with respect to each other.

TIME CANCEL—Control of variable reflector in an MTI radar system to adjust PRR to length of delay line.

TIME CONSTANT—Refers to AJ control for adjustment of circuit time constant (product of RC.)

TORQUE AMPLIFIER—Used in gyro flux gate compass system to amplify the error signal developed between the magnesyn in the master indicator and the autosyn in the torque unit.

TORQUE UNIT—A unit attached to the base of the spinner in H2X (AN/APS-15 radar) which turns the stator of a synchro so that the direction of the antenna is always referred to true north. Used for azimuth stabilization of the PPI pattern.

TR BOX—Transmit-receive resonant cavity to keep transmitted pulse out of receiver. See *Duplexer.*

TRACE—Visible line which appears on the screen of a CRT.

TRACK—(1) The geographical path of a moving body, or the path relative to the medium in which the body is moving. (Since own vessel, target, and torpedo all move in the same medium, track is taken to mean path relative to the water, and current is not considered.) (2) The actual course or direction between stations on the surface of the earth that an aircraft has traveled.

TRACKING—(1) The process of following a target by means of radar indications. (2) The term used to indicate that all tuned circuits in a receiver are properly aligned throughout the entire tuning range.

TRACKING SPOT—Moving spot on a type B indicator for target indication.

TRAIN—To control motion in azimuth or bearing, as a gun or an antenna.

TRAIN ANGLE—(For two-axis stabilization.) This is the angle, measured clockwise in the ship's deck as seen from above, from the forward end of the fore and aft axis of the ship to a plane perpendicular to the deck, through the target. In three-axis stabilization, this plane is perpendicular to the horizon.

TRAIN INDICATOR UNIT—Contains bearing synchros and training controls.

TRAIN ORDER—Training a spinner on a target is generally accomplished by means of a hand crank or motor and a servo system. The voltage sent through the servo system resulting in rotation of the spinner about its own axis is called the train order.

TRAINER—A system used for training radar operators. Simulates signals received under operating conditions in the field.

TRAINING CONTROL AMPLIFIER (TCA)—Control of power supplied to antenna training motor.

TRANS OFF-ON—Control of high voltage to transmitter.

TRANSFORMER—A component composed of two or more coils in close proximity to one another. The flow of alternating current, or pulsating direct current, through the first coil, or primary causes a magnetic field to build up and collapse in accordance with the current flow. This building up and collapsing of the magnetic field induces a voltage in the second or secondary coil. The amplitude of the secondary voltage is primarily dependent on the turns ratio of the windings. Transformers are used to couple from one circuit to another when d-c isolation is desired. Also to step-up or step-down a-c voltages.

TRANSIENT—The instantaneous surge of voltage or current which usually occurs at random intervals.

TRANSIT TIME—The time required for an electron to leave the cathode and arrive at the plate in a vacuum tube.

TRANSITRON OSCILLATOR—A pentode vacuum tube used as a generator of sinusoidal oscillations. The negative resistance characteristic of the screen grid of a pentode is used.

TRANSMISSION LINE—Any set of conductors used to carry signals or energy from one location to another.

TRANSMITTER—A term applied to that part of a radio or radar set where the r-f oscillations are generated and/or amplified. See *Radar Transmitter.*

TRANSMITTER PULSE—The r-f pulse generated in the transmitter. Sometimes called direct pulse, initial pulse, radar pulse, or main bang.

TRANSPONDOR—A combined receiver-transmitter, fitted in all friendly aircraft and ships, which receives a challenge pulse from an *Interrogator* and automatically returns a signal on the same frequency (or a different frequency, depending on the IFF system in use). The form and duration of the reply signal are controlled by a coding system.

TRAVELING WAVE—The resulting wave, guided or unguided, which carries energy from one point to another in space.

TRAPPING—A type of radio wave propagation in which the radiated rays are bent excessively by refraction in the lower layers of the atmosphere. This bending creates an effect much as if a duct or waveguide had been formed in the atmosphere. The duct, which may be either elevated or ground based, is able to guide part of the radiated energy over distances far beyond the normal radar range.

TRAPEZOIDAL GENERATOR—A vacuum tube stage designed to produce a trapezoidal voltage wave.

TRAPEZOIDAL WAVE—A waveform of trapezoidal shape. (A square wave on which a saw-tooth is superimposed.) It is the voltage wave necessary to give a linear deflection current through the coils of a magnetic CRT.

TRAVELING DETECTOR—A probe mounted on a slider and free to move along a longitudinal slot cut in a waveguide or coaxial transmission line. The traveling detector is connected to auxiliary measuring apparatus and forms a means of examining the relative magnitude of any standing waves that may be present in the system.

TRIGGATRON—High-pressure triggered spark-gap modulator.

TRIGGER—Any short pulse, positive or negative, which can be used to set into motion a chain of events. Used to synchronize the operation of the various units of a system. 1. *Calibration Trigger:* Trigger supplied to range calibrator. 2. *Coordination Trigger:* Trigger supplied to IFF coordinator. 3. *Delayed Trigger:* Trigger supplied by Delay Unit to give delayed operation, as with delayed sweep. 4. *IFF Trigger:* Trigger supplied to IFF interrogator. 5. *PPI Trigger:* Trigger supplied to PPI unit. 6. *Pre-Trigger:* Trigger delivered to sweep and indicators ahead of the time of the transmitted pulse. 7. *Radar Trigger:* Trigger supplied to the system from the modulator or transmitter pulse. 8. *Range Indicator Trigger:* Trigger supplied to the "A" scope, Range indicator. 9. *STC Trigger:* Trigger supplied to the sensitivity time control circuit of the receiver. 10. *Synchronized Radar Trigger:* Radar trigger which has passed through a delay line so as to be coincident with the corresponding video.

TRIGGERED SPARK GAP—A fixed spark gap in which the discharge passes between two electrodes and is struck (started) by an auxiliary electrode, the trigger, to which low-power pulses are applied.

TRIMMER CAPACITOR—A small adjustable capacitor, usually adjusted with a screw driver, and used in the tuning or trimming circuits of radio receivers and other radio apparatus to permit accurate alignment of these circuits.

TRIODE—An electronic vacuum tube in which three elements —a cathode, control grid, and plate—are used. Used as an amplifier.

TRODIO—Tropospheric observations of temperature and moisture conditions affecting radio or radar propagation.

TROMBONE—A U-shaped adjustable coaxial line matching assembly.

TROPOSPHERE—That part of the earth's atmosphere below the stratosphere in which temperature generally decreases with altitude, clouds form, and convection is active. Region which causes refraction and trapping.

TRUE—(1) Bearing of target with true north as reference. (2) Designation of synchro data from the system which gives antenna true bearing.

TRUNCATED PARABOLOID—A paraboloid in which a portion of the top and bottom has been cut away in order to reduce the vertical aperture and thus broaden the vertical width of the radar beam.

TUBE HOURS—Designation of tube life meter.

TUNABLE ECHO BOX—An echo box consisting of an adjustable cavity operating in a single mode. If calibrated, the setting of the plunger at resonance will indicate the wavelength.

TUNE SET—Control for manual adjustment of receiver to desired frequency.

TUNED CIRCUIT—A circuit consisting of inductance and capacitance which can be adjusted for resonance at a desired frequency.

TUNING—The process of varying the inductance or capacitance in an LC circuit to provide resonance at a desired frequency.

TURNSTILE ANTENNA—Consists of two linear antennas, lying in a plane, and crossing one another without electrical contact at their centers. If the angle between the two is 90°, the length of each element equal to a half wavelength, and the currents 90° out of phase, the directional pattern in the plane of the antenna elements is nearly circular.

TWO-AXIS STABILIZATION—See *Stabilization.*

UHF—Ultra-high frequencies (300 to 3,000 megacycles).

UNBLANKING PULSE—Voltage applied to CRT to overcome bias and cause trace to be visible. Intensifier pulse.

UNDER CURRENT RAISE—Relay adjustment.

UNITS OF RADAR SYSTEM—Antenna Assembly, Antenna Pedestal, Auxiliary Control Unit, Bearing Indicator Unit, Converter Unit, Dehydrating Unit, Delay Unit, Deviation Alarm, DG Synchro Amplifier Unit, Directional Coupler, Echo Box, Echo Box Antenna, Elevation Indicator, General Control Unit, IFF Coordinator Unit, Indicator Console, Line Switch, Line Transformer, Load Divider, Main Control Unit, Manual Elevation Unit, Modulator Unit, Monitor Receiver, Monitor Scope, PPI Unit, PPI Driver Unit, PPI Repeater, Pre-Amplifier, Power Equipment, Pulse Synchronizer Unit, Pulse Timer, Radar Distribution Switchboard, Radar Receiver, Radar Repeater Adapter Unit, Radar Selector Switch, Radar Transmitter, Range Calibrator Unit, Range Indicator Unit, Range Unit, Rectifier Power Unit, Receiver, Reflectometer, Regulated Rectifier Unit, Servo Amplifier Unit (Train, Elevation, PPI, Cross Level, Level, Roll, Pitch, O.S.C., etc.), Stable Element, Standing Wave Indicator, Synchroscope, Test Amplifier Unit, Train Indicator Unit, Training Control Amplifier Unit, Transmission Line, Transmitter, Transmitter-Receiver Unit, Trigger Delay Line, Trigger Unit, Vacuum Tube Voltmeter, Video Amplifier Unit, Voltage Regulating Transformer, Waveguide, Wires and Cables.

UNSTABILIZED—Refers to an antenna of which the base is locked in deck plane, so that no correction can be applied to offset roll and pitch of the ship.

V CENTER—Vertical centering of scope pattern.

VACUUM TUBE—A device consisting of a number of electrodes mounted in an envelope or housing from which practically all air has been removed. Also called an electronic tube.

VACUUM TUBE VOLTMETER—A test instrument which utilizes the rectification characteristic of a vacuum tube for measuring voltages without materially affecting the circuit to which the instrument is connected.

VARIAC—A type of manually adjusted autotransformer generally used to adjust line voltage input.

VELOCITY CONTROL—Variation of sweep rate on MTI velocity indicator CRT.

VELOCITY MERIT—Ratio of velocity (in degrees per second) to angular lag (in degrees) over linear range of the servo system.

VELOCITY MODULATION—The speeding up or slowing down of electrons in an electron stream to produce "bunches" of electrons whose energy is taken up in a "catcher" cavity to produce high-frequency oscillations.

VELOCITY MODULATED TUBE—A vacuum tube oscillator which produces high frequency oscillations induced by the fields associated with "bunches" of electrons in transit.

VELOCITY OF LIGHT—A physical constant equal to 2.99796 x 10^{10} centimeters per second. More conveniently, the velocity of light can be expressed as: 186,280 statute miles per second; 161,750 nautical miles per second; 328 yards per microsecond.

VERTICAL POLARIZATION—Electric field (E vector) perpendicular to the horizon. An antenna in which the dipoles are vertical is vertically polarized.

VERTICAL SPOT LIMIT—Control of tracking spot on a type B indicator.

VHF—Very high frequencies (30 to 300 megacycles).

VIBRATION ISOLATION—The property of a shock mount by which the applied vibration amplitudes are attenuated. The vibration frequencies generally encountered are 1000-3000 vibrations per minute, on aircraft, and 300-1200 vibrations per minute on ships.

VIBRATOR—A device used to change d-c power to a-c in order that the alternating voltage so produced may be stepped up or down by a transformer, and used to supply power to radio equipment. This device uses a vibrating vane driven by a coil as a means of opening and closing contacts which cause the output current to alternate in direction. By suitable arrangement, a vibrator can also be used to rectify alternating currents.

VIDEO—1. A term used to include a wide band of frequencies extending from approximately 60 or 100 cycles per second out to several megacycles per second. 2. The output voltage of a detector, or the signal voltage applied to a radar indicator.

VIDEO AMPLIFIER—A wide-band amplifier capable of amplifying video frequencies. Used for amplifying pulses in radar and television. See *Pulse Amplifier.*

VIDEO EQUALIZER—Control for change of video gain with sweep radius or sweep rate.

VIDEO FREQUENCY—See *Video.*

VLF—Very low frequencies (10 to 30 kilocycles).

VOLTAGE DIVIDER—A group of resistors, capacitors, or inductors placed in series and having one or more fixed or adjustable contacts along its electrical length in addition to the customary two end terminals. The total available voltage is applied between the two end terminals and desired portions of this voltage are obtained from any two terminals on the voltage divider.

VOLTAGE DOUBLER—A rectifier circuit which gives a pulsating d-c output nearly double the a-c input from the power transformer, or voltage source.

VOLTAGE REGULATING TRANSFORMER—Saturated-core type of transformer which holds output voltage to within a few percent (± 5%) with input variations up to ± 20%. Considerable harmonic distortion results unless extensive filters are employed.

VPR—Virtual PPI Reflectoscope. A device for superimposing a virtual image of a chart on the PPI pattern. The chart is usually prepared with white lines on a black background to the scale of the PPI range scale. See *NMP*.

VR TUBE—Gas-filled electronic tube which has the property of maintaining a nearly constant voltage across its terminals over a considerable range of current through the tube. Used in electronic voltage regulators.

VTVM—Vacuum tube voltmeter.

WATTMETER—An instrument for measuring electric power, and provided with a scale usually graduated in milliwatts, watts, or kilowatts.

WAVE—A disturbance which is propagated in a medium in such a manner that at any point in the medium the displacement is a function of the time, while at any instant the displacement at a point is a function of the position of the point.

WAVE FRONT (OF AN IMPULSE)—That part of a wave (in time or distance) between the initial point of the impulse and the point at which the impulse reaches its crest value.

WAVEGUIDE—A hollow pipe, usually of rectangular form, used as an r-f transmission line. The dimensions of the pipe are determined by the wavelength to be transmitted by the pipe. There are other types of waveguides, such as solid dielectric cables, through which it is possible to transmit energy. Waveguides may be straight, twisted, curved, tapered, or flexible.

WAVEGUIDE ELBOW—A bend in a waveguide.

WAVEGUIDE PLUNGER—A movable shorting plate, used to vary the length of a resonant section of waveguide.

WAVEGUIDE SWITCH (COAXIAL SWITCH)—A transmission line switch for transferring Transmitter-Receiver Unit from one antenna to another or to a Dummy Load.

WAVELENGTH—A wavelength is the distance traveled in one period or cycle by a periodic disturbance. If the distance between corresponding phases of two consecutive waves of a wave train. Wavelength is the quotient of velocity by frequency.

WAVEMETER—An instrument for measuring wavelength.

WAVE SHAPE—The graph of the wave voltage or current as a function of time.

WEIN BRIDGE OSCILLATOR—A sine-wave oscillator which utilizes a resistance-capacitance bridge to provide the regenerative feedback voltage. The RC bridge is electrically connected as a Wein Bridge circuit.

WHISKER—The sharpened metal wire in contact with the crystal in a crystal mixer.

WINDOW—Metal foil strips dispersed by rocket, shell, or aircraft for the purpose of jamming by multiple false targets.

WING SPOT GENERATOR—An electric circuit which grows wings on the video target signal of a type C indicator. These wings are inversely proportional in size to the range.

WINGS LEVEL—Sensitivity of wing amplifier in type C indication.

WOBBULATOR—RCA frequency-modulated signal generator.

WOGGLE JOINT—A flexible joint in a transmission line or waveguide.

X AXIS—The horizontal axis of a cathode-ray oscilloscope, as distinguished from the vertical, or Y axis, and the intensity modulation, or Z axis. It is usually an adjustable linear time base.

Y AXIS—The vertical axis. Used to describe deflection of the electron beam in the vertical direction in cathode-ray oscilloscope tubes, as opposed to deflection on the X, or horizontal axis.

YAGI ANTENNA—A type of directional antenna array usually consisting of one driven ½-wavelength dipole section, one parasitically excited reflector, and several parasitically excited directors.

YAW—The angular difference between course and heading. The amount that a ship is "off her course" at any given instant. Measured to the right or to the left, in degrees, from course to heading.

YOKE—A group of coils placed around the neck of an electromagnetic cathode-ray tube for purpose of deflection. They are wound and shaped to provide a uniform magnetic field in the area through which the electron beam passes. The magnitude of the field, and hence the amount of deflection, varies in accordance with the current through the coils.

Z AXIS—An attempt to show a third dimension on the two-dimensional screen surface of a cathode-ray tube by applying the third variable to the control grid of the tube, this variable showing up as a change in intensity.

ZERO SET—Control for adjusting range counter to give correct range.

ZONE BLANKING—A method of turning off the CRT during part of the sweep of the antenna.

ZONE PLATE ANTENNA—A rapid scanning antenna, in which the reflector consists of arcs of confocal parabolas with focal lengths which differ by $\lambda/2$ and which lie close to a circle centered at the focus.

INDEX

A

A band 153
A scope 18
ABK IFF equipment 153
Absorption of r-f energy by atmosphere 69
Accuracy
  altitude 96
  bearing 92
  range 87
AFC 112
AGC 70
Air-search radar applications 22
  characteristics 29, 35, 36, 49, 56, 60
Alignment
  of echo and range marker 87
  of optical and radar axes 94
Altitude computer 103
Altitude determination 96, 107
  accuracy 96
  effect of trapping 74
  resolution 103
  reliability 104
Altitude resolution of IFF 164
Ambiguous height finding 103
AN/APX-1 IFF equipment 153
AN/APX-2 IFF equipment 153
AN/CPN-3 radar beacon 168
AN/CPN-6 radar beacon 168
Anomalous propagation ..... see Trapping
AN system of nomenclature 4, 5
Antenna
  beam distortion 94, 163
  beam width 94
  coverage 161
  directivity 67, 84
  height, effect of on maximum range 84
  installation 117
  maximum range 84
  pattern 13, 67
  side lobes 67, 114, 162
  system 7
Anti-jamming 131, 136
Applications of radar 22-24
Atmospheric noise 81
Attenuation of r-f energy 68, 79
Aurora Borealis 81
Automatic Frequency Control 112
Automatic Gain Control 70
Automatic tracking 87

B

B scope 18, 145
Beacon ..... see Radar Beacon
Beacon coding 167
Beam width 94
Beam width distortion 121
Bearing
  accuracy 92, 145
  of IFF 162
  of jammer 136
  reliability 96
  resolution 2, 94
Bending of radio waves 61-65, 71, 74
Birds 69, 121
BK IFF equipment 153
BL IFF equipment 156
Blind zones
  near shore line 121
  nulls 65, 159
  on some relative bearings 115
  over land 123
  overhead 87, 104, 119
  radar shadows 123
BM IFF equipment 156
BN IFF equipment 156
BO IFF equipment 156
Burning of VG screen 148

C

Calibration of fade charts 98
Cancellation of radio waves 65
Capabilities of radar 21-60
Cathode-ray oscilloscope 2
Cathode-ray tubes 7-12
  dark trace 147
  definition on screen 90
  electromagnetic 9, 11
  electron beam 8
  electron gun 9
  electrostatic 8, 10
  fluorescent screen 9
  use in radar 8
Change No. 50 to SG radar 79, 85, 88, 90
Characteristics of pips 24, 111, 127
Characteristics of shipborne radars 25-60
  air search 29, 35, 36, 49, 56, 60
  fire control 38-45, 54
  height-finding and low-angle search 32, 33, 37
  submarine 56-60
  surface search 30, 31, 34, 50-53, 57-59
Chopped reply on G band 156
Cloud echoes 69, 80, 121
Coding
  of beacon reply 167
  of IFF reply 154
Communication by means of radar 151
Communications interference from IFF 164
Components of radar system 7
Conical scanning 100
Corner reflector 70
Cosecant-squared beam 68
Countermeasures 131
Counting down 155
Coverage patterns 116
Coverage of radar
  found by interception 132
  roll and pitch of ship 78
  sea return 79
  trapping 72-76
CRT ..... see Cathode-ray tube
Cursor on PPI 93
Curvature of the earth 99
Cut-out bearings 92

D

Dark-trace tube 147
Deception 131, 138
  detection of 140
Decoys 139
Definition of pattern of indicator 90
Definitions of radar terms ..... see Glossary
Deflection presentations 17-18

Delay box 142
Delay
in beacon response 169
in IFF response 164
Delayed PPI 142
Deployment of frequencies 137
Destructive interference 65
Destructors 157
Detection
of aircraft over land 123, 125
of deception 140
of low-flying planes 66
Detonators 157
Development of IFF 151
Difficulty of producing effective jamming 135
Diffraction of radio waves 64, 69, 132
Direct interrogation of IFF 164
Directivity of antennas 67, 84
Distortion
of antenna beam 94, 163
on B scope 146
on delayed PPI 144
of echo pulse 90
in SX off-center PPI 150
Double bounce calibration 116
Double-lobe system 14
Double-trace indicator 154, 164
DRT connection to RPPI 150

E

Early warning by intercept receivers 132
Echo interpretation 24, 111, 127, 134, 140, 146
Echo strength
effect of propeller rotation on 101
fluctuation in 70
non-uniform propagation pathway 70
size of target 69
target illumination 69
trapping 72-76
Electron beam 8
Electron gun 9
Electronic deception 139
Electronic jamming 134
Elevation of antenna to detect aircraft over land 125
Emergency IFF 154, 159
Erasing VG pattern 147
Errors in IFF operation 158
Evasion 131, 140
Evasive action
approach in long glide 105
approach low and climb 105
cloud cover 80
dive and retire "on the deck" 105
effect of on altitude determination 97
effect of trapping on 75, 76
flying down nulls 65, 105
taking advantage of poor altitude resolution 104
Expanded PPI 142, 148
Expanded sweep
in jamming 138
range accuracy 87
range resolution 90

F

Fade chart 15, 98
for IFF 159
Failure
of communications 75
of IFF 158
False contacts 65, 96, 121
False echoes 114-121
blind zones 116
multiple reflections 115
phantom 69, 121
second trip 119
side lobes 67, 114
storms 79
see False contacts
False shore line on PPI 128
Fast erase position 147
Fast Time Constant video coupling ..... See FTC
Fire control radar
applications 23
characteristics 38-45, 54
First detection range as a means of estimating altitude 97, 105
Fixed range errors 88
Fluctuations of echoes 70
Flying down nulls 65
Flying fish 69, 121
Fluorescent screens 9
Formation of duct 71
Frequency
bands 2
deployment of 136
shifting 137
that can be trapped 72
FTC
AJ circuit 138
cloud echoes 80
land clutter 123
sea return 79, 123
Window 138

G

G band 153
chopped reply 156
operation 156
Gap coding 167
Geographical plot of second trip echoes 121
Glinting 69
Glossary of radar terms 171
Grass 83
Guided propagation ..... see Trapping

H

Heaviside layers 61
Height-finding and low-angle search radars
applications 22
characteristics 32, 33, 37
Holding period 156

I

IAVC
AJ circuit 138
cloud echoes 80
land clutter 123
sea return 79, 123
Window 138
Ice on antenna 79
Identification 151
IFF
A band 153
applications 23, 24
code on PPI 159
coding systems 153
coordination unit 155, 164
coverage 159, 161
echoes 161
G band 153
indicators 154
range 161
silence 161
survey 158

Index of refraction 62, 63
Indicator 7
Information gained through interception 132
Intermittent operation of radar 132
Intensity modulated presentations 18-20
  vulnerability to jamming 134
Interception 131-133
  effect of trapping on 75
Interference 14, 131, 136
  in IFF 164, 165
Interpretation of echoes 24, 111, 127, 134, 140, 146
Interrogator 152, 154

J

J Scope 18
Jamming 131, 133-138
  AJ measures 136
  bearing accuracy during 93
  electronic 134
  effect on indicators 133
  mechanical 135
  noise jamming 138
  trainers 137
  Window 135
Jitter pulsing 133

L

Limitations of IFF system
  materiel 164
  operational 157
  propagation 159
  resolution 162
Limitations of radar
  enemy countermeasures 131-140
  external factors 61-81
  inherent 83-109
  operational 111-130
Limitations of radar beacons 169
Limiting of echo pulses 90
Line voltage fluctuations 88
Lobe pattern 65, 66, 74
Lobe switching 14, 92
  effect on beam width 95
Lobes 70, 101, 137
Long Persistence screen 147
Low-angle coverage of IFF 159

M

Manipulation of controls 111
Mast-reflection echo eliminator 115
Materiel limitations of IFF 164
Maximum range
  beacons 170
  IFF 161
  radar 25, 83
Measures for limiting interception 132
Measurement of
  altitude 14
  bearing 13
  position angle 15
  range 12, 88
Mechanical jamming 135
Meteorological factors that cause trapping 76
Meteorological measurements 77
Method of operation of radar beacons 167
Methods of radar deception 138
Microsecond 1
Minimum range
  of effective jamming 135
  of a radar 85
Minor lobe echoes ..... see Side-lobe echoes
Mark II IFF system 151
Mark III IFF system 153
Mark IV IFF system 157
  limitations 165
Mark V IFF system 157
Mark 4 radar 38, 101
Mark 8 radar 39, 40
Mark 12 radar 41, 101
Mark 13 radar 40
Mark 22 radar 42, 101, 106
Mark 26 radar 54
Mark 28 radar 43
Mark 29 radar 44
Mark 34 radar 45
Moisture lapse 71
Monsoonal climate 76, 78
"Moving" land contact 127
Moving spot scope 18, 95
Multiple IFF responses 159
Multiple reflection echoes 115

N

Navigational micro-film projector 127
Noise modulated jamming 135
Nomogram correlating antenna height and target altitude with maximum range 62
Non-standard propagation 71-78
Null altitude calculator 98
Nulls 65
  in IFF 159
  in VHF communications 66

O

Observing fades on PPI 105
Off-center PPI 148
Omnidirectional antennas 154, 156, 161
Operation of
  IFF system 153
  radar beacon 167
  transpondor 152
  VF repeater PPI 146
  VG repeater PPI 147
Operational limitations
  of IFF 157
  on radar 111-130
Operator training 132
Optical bearings 96
Optical system in VG RPPI 148

P

Passive deceptive reflectors 139
Peak power 2
Performance
  of Mark III IFF 158
  of radar
    effect of ice on antenna on 79
    effect of trapping on 75
  reports 109
Phantom contacts 121
Phase relationship of sine waves 65
Portable radar beacons 170
Power supply 7
PPI scope 20
  IFF responses on 159
Precision repeater PPI 23, 88, 144
Precision sweep 87
Prediction of non-standard propagation 76
Preventive maintenance 107
Principles of an IFF system 153
Projection repeater PPI 23, 147
Propagation of r-f energy 61-70, 159
Propeller rotation 101
PRR 1

Pulse
- definition of ... 1
- distortion of ... 90
- division ... 155
- duration ... 1
  - cloud echoes ... 80
  - maximum range ... 83
  - minimum range ... 85
  - range resolution ... 88

R

R scope ... 18
Radar
- horizon ... 63
- installations on ships
  - large ships ... 27, 28
  - small ships and auxiliaries ... 46-48
  - submarines ... 55
- nomenclature ... 3
- operator
  - skill and experience ... 108
  - training ... 112
- range vs. antenna height ... 61, 62
- shadows ... 123
- silence ... 132
- system, components of ... 7
- terms ... 1, 2, 171

Radar beacons—racons ... 167-170
- applications ... 24
- capabilities and limitations ... 169
- coding systems ... 167
- method of operation ... 167
- racon list ... 167
- range performance ... 169

Radar Planning Device ... 129
Radar recognition systems—IFF ... 151-165
Radio-frequency pulse ... 1
Radio homing beacons ... 168
Range
- accuracy ... 87
- coding ... 168
- estimation ... 88
- maximum ... 83
- measurement ... 12
- minimum ... 85
- reliability ... 92
- resolution ... 2
  - —of IFF ... 164
  - —of radar ... 88
- ring ... 141
- scales ... 141

Ranging on land ... 125
Receiver ... 7
- distortion ... 90
- gain, effect on
  - apparent beam width ... 94
  - range resolution ... 90
  - side lobe echoes ... 114
- noise ... 83, 111
- recovery time ... 85
- sensitivity ... 84

Recognition ... 151
Reflection of radiated energy from flight deck ... 99
Reflection of radio waves from sea ... 65-67
- attenuation ... 68
- cancellation of radio waves ... 65
- destructive interference ... 65
- extension of range ... 66
- position angle measurement ... 100
- reliability of radar altitude ... 104

Refraction of radio waves ... 61-64
Reliability
- radar altitudes ... 104
- radar bearings ... 95
- radar equipment ... 108
- radar ranges ... 92

Repeater plan position indicators ... 23, 141-150
Repetition rate ... 84
- revealing second trip echoes ... 119
- VG repeater PPI ... 148
- VK repeater PPI ... 150

Resolution ... 2
- altitude ... 103
- bearing ... 95
- expanded PPI ... 142
- of IFF ... 162
- range ... 88
- VG repeater PPI ... 147
- VK repeater PPI ... 149

Responsor ... 153, 154
RHI ... 102
Round trip echoes ... 116
RPD ... 129

S

SA radar ... 49
SC radar ... 29
Scharnhorst and Gneisenau ... 136
SD radar ... 56
Sea return ... 78
- minimum range ... 85

Second trip echoes ... 119
Self-triggering of IFF ... 164
Sense of direction ... 100
Sensitivity
- of IFF transpondor ... 164
- of radar receiver ... 84

Sensitivity-time control ... see STC
SF radar ... 50
SG radar ... 30
- change No. 50 ... 79, 85, 88, 90

SG-3 radar ... 31, 80
Shifting frequency ... 137
Ship's heading marker—SHM ... 112
Side lobes ... 67
- false echoes ... 114
- in IFF ... 162
- minimum range ... 85

Single-lobe system ... 13, 92
Size
- of indicator screen ... 90
- of target ... 69, 84
- bearing accuracy ... 94

SJ radar ... 57
Skill and experience of radar operator ... 111
Skewed lobe ... 94
SL radar ... 51
SM radar ... 32, 66, 92, 103, 106
SO radar ... 52
Spotting shell splashes ... 129
SP radar ... 33, 66, 92, 103, 106
Speed of target ... 92
SQ radar ... 34
Squitter ... 164
SR radar ... 35
SR-2 radar ... 36
SR-3 radar ... 92
SS radar ... 58
ST radar ... 59
Stabilized antennas ... 78
Standard atmosphere ... see Glossary
Standard RPPI ... 23, 141
Station keeping ... 88

STC
dual use of set 112
minimum range 85
sea return 79
side lobes 67
St. Elmo's fire 81
Storms 79
SU radar 53
Submarine radar
applications 22, 23
characteristics 56-60
Substandard propagation 75
Super-refraction ..... see Trapping
Superimposed fade charts 107
Suppression of IFF 165
Surface-search radar
applications 22
characteristics 30, 31, 34, 50-53, 57-59
SV radar 60, 92
Sweep length, effect of PRR on 84
SX radar 37, 66, 92, 102, 106, 148
System performance 111

T

Tangent bearings 128
Target angle 91
Temperature inversion 71
Theory of radar 7-20
Time sharing 153, 156
Timer 7
Trade winds 76, 78
Training
of maintenance personnel 107
of radar operators 112, 136
Transmitter 7
Transmission line loss 84
Transpondor 152, 153
operational check 165
tuning change 164
Trapping 71-78
altitude determination 99
apparent performance of equipment during 75
conditions for existence of 71, 76
fade chart 74
fading of echoes during 75
failure of communications 75
frequencies than can be trapped 72
prediction of 76
radar coverage 71-75
seasonal variation 77
Trigger delay 88
Triggering of IFF by enemy radar 161
Tuning radar to beacons 169
Type of target 69, 85, 125
Types of indicators 17-20, 141-150
interpretation of echoes 25
vulnerability to jamming 134
Types of jamming 134
Types of radar beacons 168
Types of scan 17-20

U

Universal IFF system 152
Use of radar in piloting 127
Uses of radar beacons 167

V

Variation in echo strength 69
VC repeater PPI 141
Vertical antenna pattern 14
VF repeater PPI 88, 144
VG repeater PPI 134, 147
burning of screen 148
VH repeater PPI 142
Video 2
Virtual PPI reflectoscope 127
VK repeater PPI 148
Voltage fluctuation 108
VPR 127

W

Wavelength 2
that can be trapped 72
Weather 78-81
Weather conditions that indicate trapping 77
Window 135, 138

Y

YJ radar beacon 168

Z

Zero set 88